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High Resolution Sequence Stratigraphy, Sedimentology and Paleoenvironmental Studies of Late Eocene – Late Oligocene Sediments, Greater Ughelli Depobelt, Niger Delta, Nigeria

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Abstract

This paper presents the result of a sequence stratigraphic study of well-'B' sediments in the Niger Delta. It also attempts to improve the sequence stratigraphic model of the well by integrating biostratigraphic/biofacies paleobathymetry, wirelines logs and lithological datasets. Studies carried out on the sediments of well -'B' yielded significant microfaunas after foraminifera analysis was undertaken. All the inferred datum corresponding to the encountered key candidate surfaces were analysed and also used for the dating of the well. Sequence stratigraphic interpretation of this well provided adequate understanding on the existence of the parasequences and parasequences sets which defined the depositional pattern in conjunction with the Maximum Flooding Surfaces and Sequence Boundaries. This provides a better resolution in term of genetic sequences thereby ascertaining the respective pay zones within the well. Well log shapes, microfauna abundance/diversities and paleobathymetry of well-'B' revealed Non-marine to Upper bathyal paleoenvironment of deposition characterized by phases of delta progradation and retrogradation. Four Marker shales, characterized by *Chiloguembelina cubensis* and/or *Globorotalia opima opima* (28.1Ma*), Uvigerinella sparsicostata* (31.3Ma), *Spiroplectammina wrightii* (33.0Ma) and *Hopkinsina bononiensis*(34.0Ma) were encountered and used in dating the key bounding surfaces with the aid of the Niger Delta chronostratigraphic chart. The analysis reveals that the sediments of well-'B' penetrated the Late Eocene - Late Oligocene times. All the interpreted systems tracts in this well give clue for prospect recognition, risk analysis and evaluation of new opportunities. In addition, paleo-environmentally diagnostic benthonic and planktonic taxa are used in this study to aid in modelling the lateral continuity of intra-reservoir mudstones utilizing all the analysed microfauna zones. The applicability of biostratigraphic principles as used in this study stands to aid optimization in the reservoir appraisal and development thereby increasing impact and value of the discipline in hydrocarbon generation within Niger Delta and giving it a central role in integration of reservoir description and sequence stratigraphic framework erection.

Keywords: Sequence Stratigraphy, Systems tracts, Biostratigraphy/biofacies, Sedimentology, Paleobathymetry, Well logs, Greater Ughelli depobelt..

Introduction

Sequence stratigraphic concept as a recent methodology for stratigraphic interpretation is a process-oriented approach for the interpretation of sedimentary environment and has been found to be applicable to the siliclastic successions in the Niger Delta petroleum province. It therefore, draws upon an understanding of depositional processes within a sedimentary basin and the factors that directly influence them which includes tectonism, sea-level changes, subsidence rates, sediments supply, climate conditions and basin geometry and/or heterogeneities (Zecchin et al., 2006). Sequence stratigraphic principle also describes the linkage between sedimentation patterns in different parts of basins and predicts the locations and extent of reservoir, seal-prone intervals, pay zones, occurrences and geometries of sedimentary facies within the basin (Lee et al., 2004). Recent studies on integrated reservoir studies relied largely on modifications of the basic sequence stratigraphic model, in which their depositional cycles occur as large scale which reveals an upward-fining and upward-coarsening succession. In-depth knowledge and application of sequence stratigraphy helps in exploitation and discovery of oil through the understanding of structural traps and the nature of the sediments geometry which enhances such discoveries. Ideally, identification and delineation of horizons in sequence stratigraphic interpretations involves multidisciplinary approach utilizing available information which include seismic profiles, well logs, ditch cutting samples/cores and biostratigraphic/biofacies datasets. The subsurface ditch cutting samples after due process normally yield biostratigraphic dataset which provide highly useful information on identifying Maximum Flooding Surfaces, Condensed sections, Sequence Boundaries and their on-going ages in million years, chronostratigraphic surfaces, paleobathymetry and climatic conditions. Facies analysis is a fundamental sedimentological method of characterizing bodies of rocks with unique lithological, physical, and biological attributes relative to the deposits. This method is commonly applied in this study to describe the sediments and/or sedimentary rocks observed within the well under study. Facies analysis is of paramount importance for any sequence stratigraphic study, as it provides critical clues for paleogeographic and paleoenvironmental reconstructions, as well as for the definition of sequence stratigraphic surfaces. Moreover, the analysis of wireline log data in a sequence stratigraphic framework makes it possible to place appropriately lithologic facies and depositional environments on a seismic section thus linking seismic facies (stratal geometries), rock properties and sedimentological facies (Balogun, 2003). Thus, expertise in these disciplines as well as an integrative strategy provides models that help to recognize and predict reservoir, seal and source rock facies and its continuities, hence reducing stratigraphic risk at the exploration and production levels and improving correlation of reservoir units for exploration and production targets.

Analysis carried out on the subsurface sediments belonging to well-‘B’ in the Niger Delta basin involves using biostratigraphic datasets for the establishment of a sequence stratigraphic framework of the environment. The sedimentological facies coupled with the understanding of the various sub-environments helps in the prediction of sand quality and development. However, the understanding of the respective sub-environments provides additional comprehensive geologic information on the sandstone architecture with respect to their spatial distribution of lithofacies, stratal geometry and its orientation. Due to the importance of potentials sandstone bodies as reservoirs constituents for hydrocarbons, there is need for a comprehensive biostratigraphic/biofacies and sedimentological studies of this sedimentary deposits. Results of the sequence stratigraphic analysis showed

that highstand system tracts are thicker than transgressive and lowstand system tracts in this study well which partly quantified this depobelt as a mature and enviable hydrocarbon zone.

This study however addresses the application of sequence stratigraphy, paleo-environment and sedimentology incorporating biostratigraphic techniques for the understanding of reservoir properties and their maturity extents. This will be used to identify untapped reservoir compartments within the field which will enhance further study of the adjoining fields for new discoveries. The objectives of the study include identification of key stratigraphic surfaces, depositional sequences and delineation of the different systems tracts and the determination of dominant trapping mechanisms in the study area. Also, systems tracts that serve as hydrocarbon reservoirs units have been identified while environments of deposition were determined using electrofacies association.

Objectives

1. Carry out detailed foraminiferal biostratigraphic /biofacies analysis of well -'B'.

2. Integrate and analyze biostratigraphic, sedimentological, composite well logs (Gamma and Resistivity) and lithological datasets.

3. Carry out detailed well log analysis of the well in other to determine depositional environments.

4. To erect sequence stratigraphic framework utilizing the entire encountered foraminiferal datum.

5. Delineation of key surfaces, recognition of systems tracts and stratigraphic identifications within the genetic depositional sequence packages.

Geological setting and stratigraphy of the Niger Delta

The Niger Delta, on the passive western margin of Africa, has been described as a classic example of continental-margin structural collapse under sediment loading (Armitage et al., 2012) and was initiated in the Early Tertiary times (Doust and Omatsola, 1990). Geographically, this sedimentary basin is located between longitude 50 and 80E and latitude 30 and 60N respectively and occupies the Gulf of Guinea continental margin in equatorial West Africa. It occupies a total area of about 7,500km2 in the Gulf of Guinea (Fig.1) with a sediment thickness up to 12,000m (Bustin, 1988).

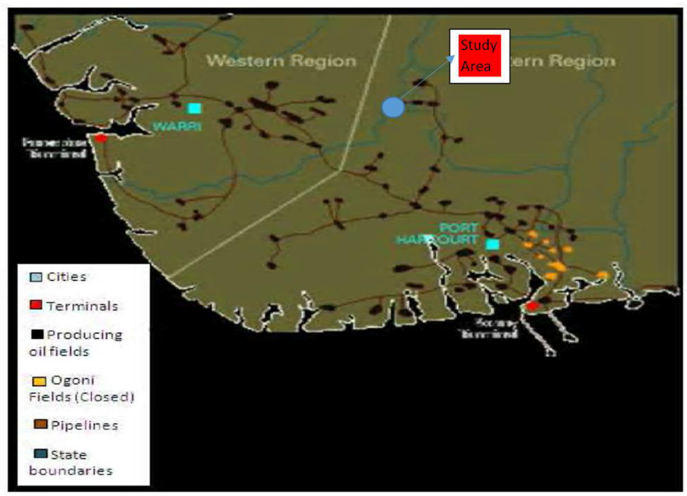

Figure 1. Niger Delta map showing well location- Well B (Modified from Imasuen at al. 2011).

The sedimentary environments of the Niger Delta serve as a classic model for high energy, wave-dominated, constructional arcuate-lobate tropical deltas (Reijers et al., 1996). The progradation of this deltaic sequence has been controlled by syn-sedimentary faults and the interplay between subsidence and sediments supply. Each depobelt contains one or more paleontologically distinct transgressive shale horizon. These transgressive shales represent interruptions in the overall regressive sequence that is probably related to sea-level rises. The fundamental trend, however, consists of a stepwise building up of offlap cycles within each depobelt that gradually progrades southward. The

result is a gradual increase in sand percentage up-section.

The Tertiary Niger Delta is composed of mega-units which are entities and are bounded North and South by major breaks in the regional dip (Benkhelil, 1987) and continues offshore into the continental shelf. Based on this note, the Niger Delta area has been a site of cyclic sedimentation and as such depositional environments of these sedimentary accumulations vary from nearshore to non-marine, marginal marine and deep water deposits (Haack et al., 2000). Sedimentological and stratigraphic descriptions of different aspect and/or sub-environments of the Niger Delta have been carried out and documented by many authors among them are Asseez, (1976) and Adeogba et al., (2005). In this same view, Edwards, (1995) documented that in deltaic and most depositional settings, sedimentation consists of stratigraphic cycles characterized primarily by alteration between more and less energetically supplied materials, such as sand and shale sediments. Three major sedimentary environments have been recognized (Short and Stauble, 1967) within the Niger Delta. In the delta top, sedimentation concentrated in numerous arcuate belts bounded by large scale regional and counters regional growth faults (Doust and Omatsola, 1990). The Tertiary Niger Delta sediments was deposited in three major sequences which have been shown by well sections drilled vertically within these environments. The Niger Delta lithostratigraphic units have been therefore reported to be strongly diachronous (Stacher, 1995). According to Merki, (1972) and Short and Stuable, (1967), many other workers and multinational companies that work in this area have recorded that the major lithostratigraphic sequences or units found within the Niger Delta formation include, the Benin Formation, Agbada and Akata Formations respectively (Fig. 2).

These formations showed intercalation of sand, shale, silt and/or sandstone facies equivalents which represent the delta plain, delta front and prodelta environments.

The Benin Formation in the Niger Delta is the upper continental deltaic plain setting. It consists of fresh water, fluviatile sands and gravels with occasional coal seams, lignites and shale beds of about 2500m thick (Fig. 3). Evamy et al., (1978) documented that this formation has 9:1 sand/shale ratio intercalations. The sand varies in grain size from fine to very coarse and sometimes pebbly in places. The sediment sorting is more or less poor and grains are subangular to well rounded, yellowish brown to clean quartz grains. Many literatures and reports from companies exploring for oil in the Niger Delta had arbitrarily defined the base of Benin Formation by the deepest fresh water bearing sandstone that exhibits high resistivity. The base of this formation is defined by the first marine deposit (Short and Stuable, 1967) and this includes massive coarse-grained sands from the non-marine (Coastal deltaic) or continental environment that make up this formation. However, Benin Formation is dated Oligocene to Recent in age. The Agbada Formation underlain the continental sand sequence of the Benin Formation and is characterized by paralic to marine deposits mainly composed of sandstones and shales organized into coarsening (shoaling) upward offlap cycles. This formation is diachronous with a thickness of about 4,500mand ranges in age from Upper Miocene in the north to Pliocene – Pleistocene in the south.

The shales sediments on the other hand are dark to light grey, hard to moderately hard and subfissile to fissile with occasional shell fragments occurrences. Conversely, Akata Formation is the basal sedimentary unit of the Niger Delta and it includes at least 6,500m of marine clays with silty and sandy interbeds (Whiteman, 1982). This formation is overlain by the

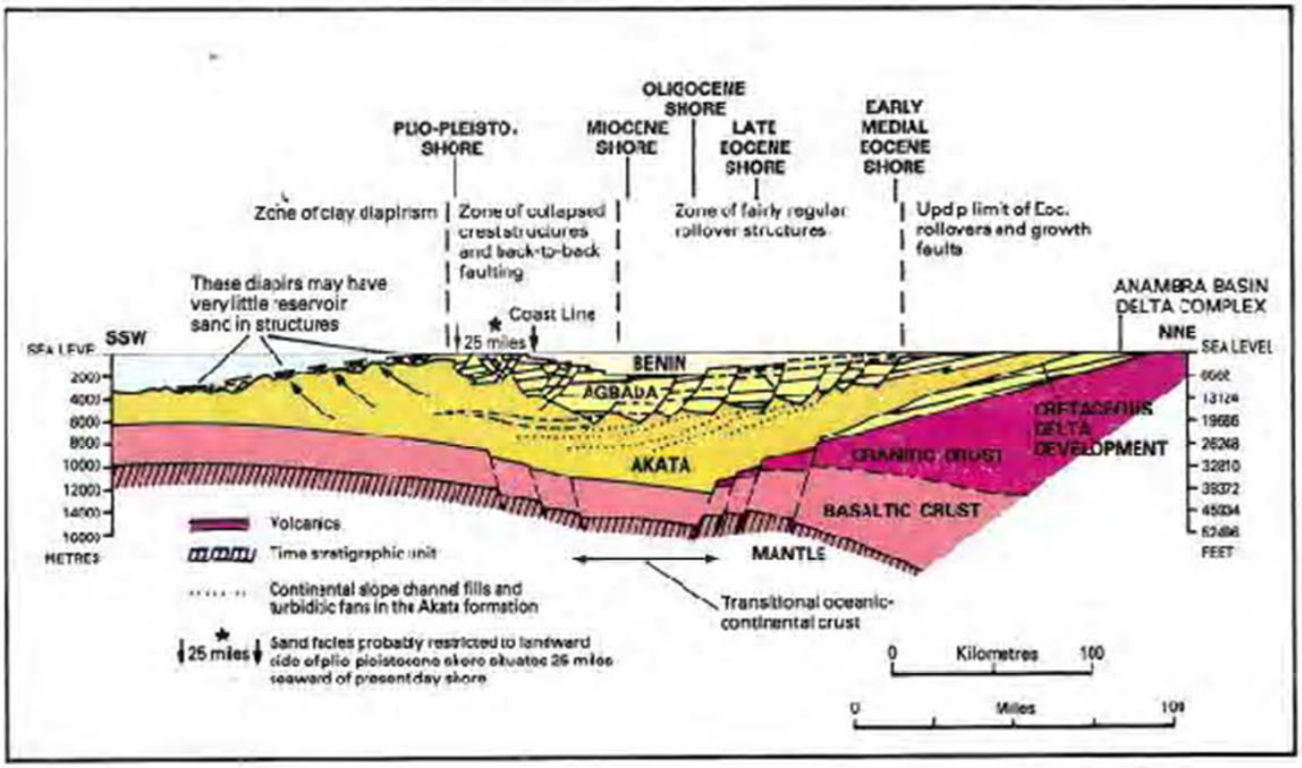

Figure 2. Niger Delta schematic dip section (After Merki, 1972).

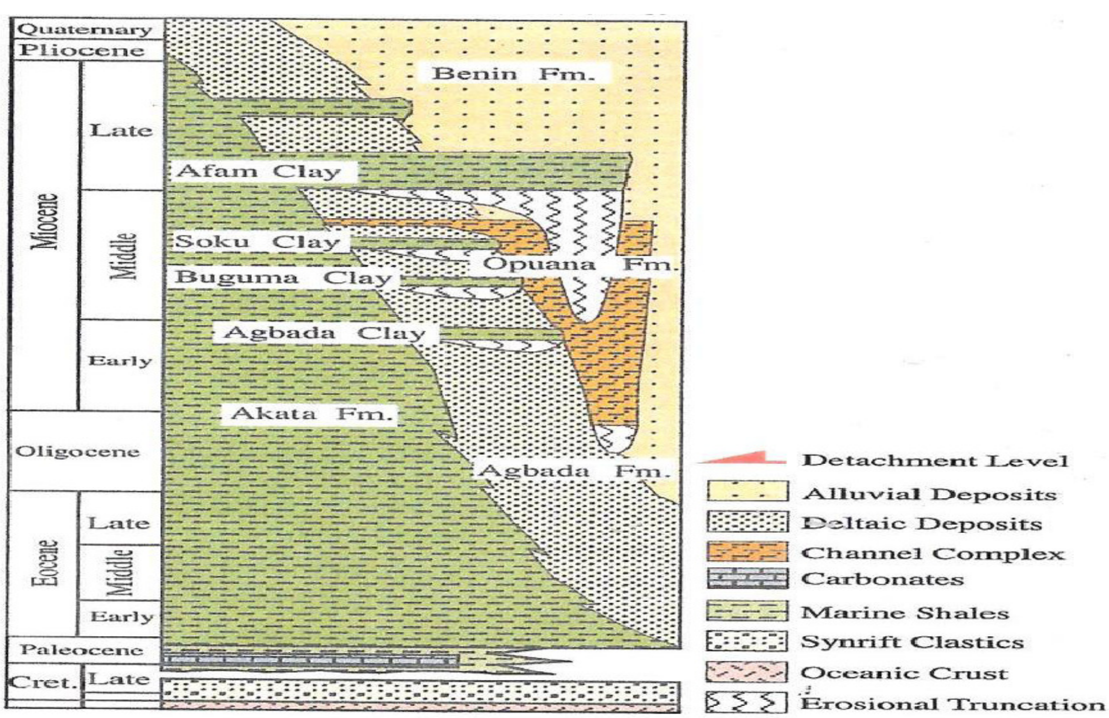

Figure 3. Stratigraphy of the Niger Delta showing various formations (Modified after Adiegbe et al. 2012).

paralic sand/shale sequence of the Agbada Formation representing 3:2 ratio of sand to shale deposits (Evamy et. al., 1978). The paralic sand/shale succession in this formation is attributed to the differential subsidence of these sediments and shifts of the delta depositional axes which cause local transgressions and regressions. In the same vein, Beka and Oti, (1995) postulated that this formation has a clastic sediment thickness of about 6,000m. The Akata Formation have traces of plant remains, minor pyrites, gluaconites, feacal pellets and mica minerals occurrences which form the accessories within this formation. This formation is rich in microfauna contents especially foraminifera. The shales lithofacies within the Akata Formation are principally uncompacted and are highly pressured (Onuoha et al., 2008). The depth to the abnormal pressure ranges from 2,000m along the shelf to 4,500m in the western Niger Delta (Owolabi et al., 1990) while Schlumbeger (1985) published that the pressure level in the uncompacted marine Akata shales is at least half times the normal hydrostatic pressure.

The deposition of the sedimentary offlap sequence over the Akata shale caused gravitational instability in the substratum, leading to deformation, upliftment of shale diapirs, faulting and erosion during the Paleocene - Late Miocene age. The Niger Delta sedimentary wedge consists of series of discrete depocenters or depobelt each characterized by an individual proximal-distal facies trend within the Agbada Formation (Reijers et al,. 1996). These depobelts are divided into five units based on the occurrence of major regional growth faults in the basin. The five depobelts; each measuring about 30 - 60km wide (Stacher, 1995) are as follows: Northern Delta, Greater Ughelli, Central Swamp, Coastal Swamp and the Offshore depobelt (Fig. 4). These depobelts are in a manner that the oldest depobelt lies furthest inland while the youngest is located in the offshore realm. Evolutionally with time, the Northern Delta depobelt evolved during Early to Middle Eocene times and was characterized by the deposition of lithofacies (mainly coarse grained sand) belonging to the Agbada Formation. A new coastline, shaped by long-shore current began to influence sediment distribution during the Oligocene and Early Miocene times. The deposition of a thick sequence of sandy sediments in the Greater Ughelli depobelt also took place during this time interval. The deposition of sediments in the Central swamp and the Northern parts of the present day Coastal swamp depobelt occurred during the Middle to Late Miocene times. The continuous progradational pattern of the delta in the Late Miocene to Pliocene times resulted in the emergence of the youngest portion of the Coastal swamp as well as the offshore depobelt. During major progradational pulses, the delta top deposits advance over the Agbada deposits. Under the influence of sediment loading within the system, new depobelt bounding faults develop and sedimentation of Agbada deposits move towards this realm which previously was distal, therefore creating a new, younger depocenter whilst the older depobelt is abandoned and covered by fluvial deposit of Benin Formation. Major regional faults thus determine the location of each depobelt. Sedimentation in the depobelts is a function of the rates of deposition subsidence with syn-sedimentary growth faults upsetting the delicate balance (Evamy et al., 1978).

The combined effect of continued sediment supply, syn-sedimentary faulting and relative sea level fluctuations gave rise to the continuous vertical cycle stacking of proximal fluvio-marine interlaminated silt, sand and clay usually followed by various types of lower to upper shoreface sands and coastal plain deposits, each vertically terminated by the next transgressive event (Weber, 1971). This action therefore resulted in the delineation of eleven well defined third order sequences which form the fundamental sequence stratigraphic building blocks of

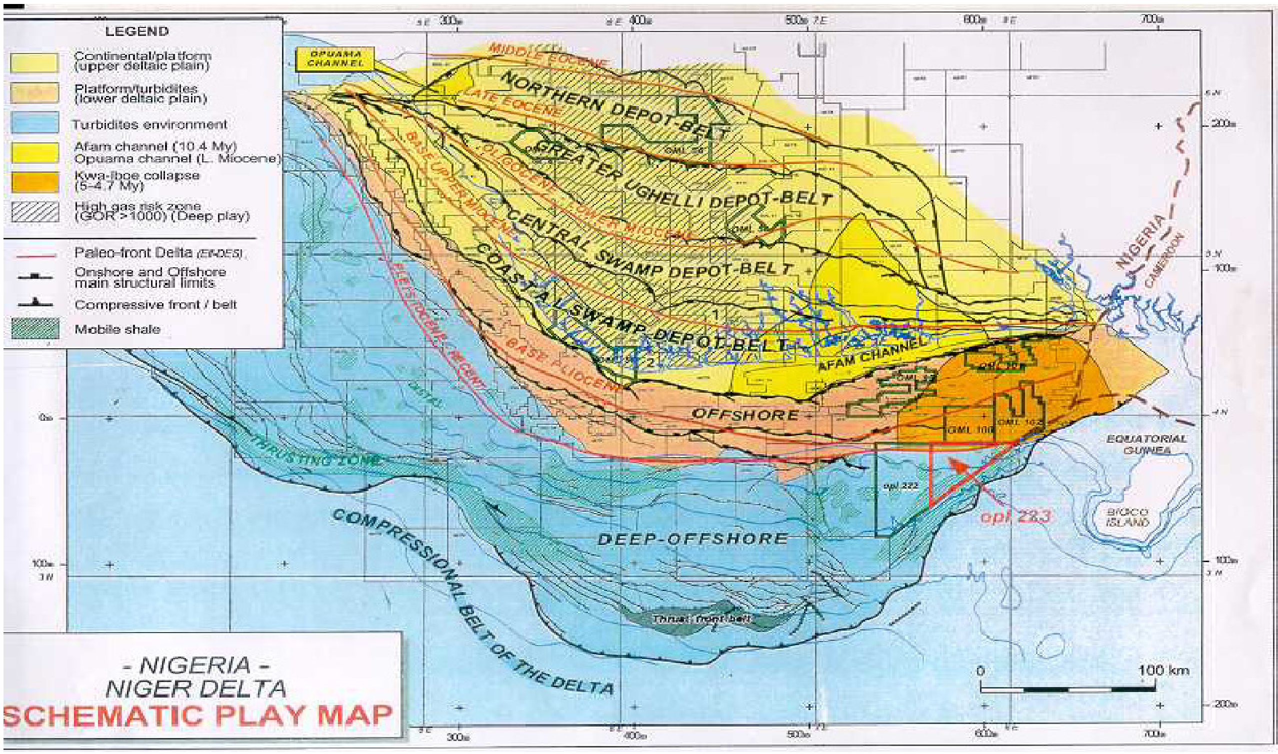

Figure 4. Paleogeography of Tertiary Niger Delta (After Ejedawe, 1981).

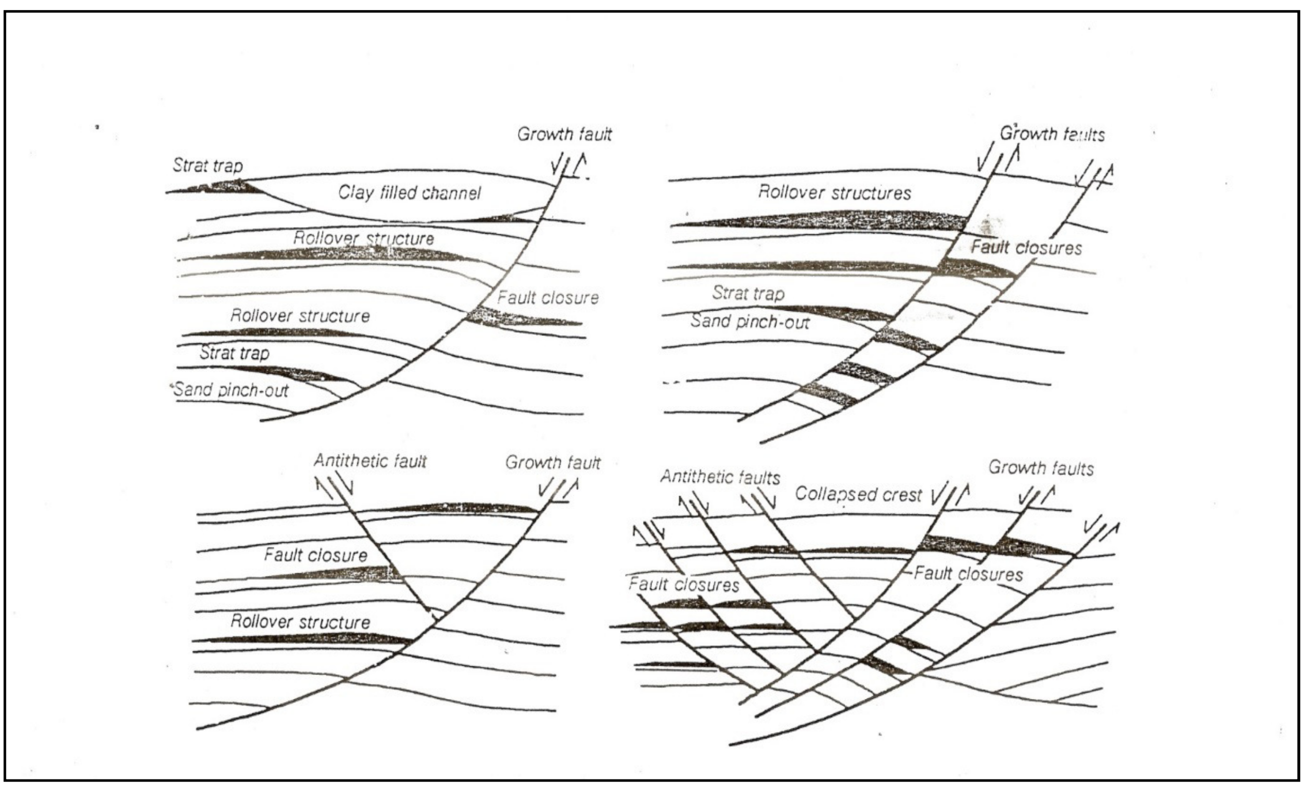

Figure 5. Typical fault and trap structures of Niger Delta.

the Niger Delta Basin (Reijers et al., 1996). On the down-thrown side of the major structure building growth faults, the paralic facies of the Agbada Formation accumulated in the depobelt when the ratio of the sand is approximately equal to or less than one. This corresponds to the active phase of subsidence in a particular depobelt. Thus syn-sedimentary faults trapped dispersing sediments into depocenters at the down-thrown side of the faults, where sediments accumulation ensured continued equilibrium and on-going deposition along the shoreface. When subsidence rate decreased, the rate of additional accommodation space reduced and alluvial continental sands of the Benin Formation rapidly advanced across the depobelt to maintain the base level of sedimentation. This will then be transferred in the down-dip direction into the adjacent depobelt that was created by younger syn-sedimentary fault systems. Further suggestion showed that fault linkage is a significant event in basin evolution, and its process may be very rapid, adding that fault linkage exerted considerable control on sedimentation and evolution of basins. In this same vein therefore, it has been further discovered that rapid sand deposition along the edge top of under-compacted clay of the Niger Delta has resulted in the development of a large number of syn-sedimentary gravitational faults. They are generated by rapid sedimentation load and the gravitational instability of the Agbada sediments pile accumulating on the mobile, uncompacted Akata shales. There is little or no growth faulting episode extending into the Benin Formation. Toe thrusting at the delta front, lateral flow and extrusion of the Akata prodelta shales during growth faulting and related extension, also accounted for the diapiric structures on the continental slope of the Niger Delta in front of the prograding depocenter with paralic sediments. Sediments within this environment are complicated by syn-depositional listric normal faults that formed as prograding deltaic sediment load underlying the under-compacted marine shales. The complexity of these structures is dependent on the overall sediment burden however, increased overburden and horizontal displacements makes accommodation to be more complex.

Growth faults comprise of antithetic faults and the major structure building faults (some of which bound the depobelt) and steep, parallel crestal faults which cut the rollover structures (Fig. 5). However, this growth faults and related rollover structures are the dominant hydrocarbon traps in the Niger Delta and these have been recognized as a controlling factor in fluid distribution within fields in the delta (Tegbe and Akaegbobi, 2000). The complexity of the structure is dependent on the overall sediments burden in the initial phase of the growth faulting while displacement only occurs along the major bounding faults; with increased overburden and horizontal displacement, accommodation becomes more complex and finally occurs along numerous small faults which form the typical collapsed crest structures.

Materials and Methods

The available materials used in this study include:

(1) One hundred and thirty-nine (139) ditch cutting samples from well ‘B’,

(2) Wireline log motifs (Gamma ray and Resistivity) and

(3) Niger Delta Chronostratigraphic chart.

The preparatory technique used for the foraminiferal biostratigraphic sample preparation for well- ‘B’ in this study followed the approach adopted by Armstrong and Brasier (2005). A total of one hundred and thirty-nine (139) ditch cutting samples composited at 10m and 8m were prepared for foraminiferal biostratigraphy in this study. The washing-soda (Na_2CO_3) method was used in this

preparation. However, this method is particularly useful when working with the Tertiary (unconsolidated) sediments as in the case of the Niger Delta. Sample list was prepared for well-'B' since the sample list was not given by the company that provided the samples. This helps to check for any missing interval/depth that may occur within the well before the samples was arranged serially. Each composited sample was treated with a small quantity (20g) of one teaspoonful of anhydrous Sodium Carbonate (Na2CO3) for thorough disintegration. Enough water was added to cover the sample and it was allowed to stand over-night. Washing of the soaked sample was achieved by using a 53 µmesh sieve with a gentle rushing-jet of water from a tap. The washed sample was dried at a minimum temperature of 200C. The dried samples were then sieved into coarse, medium and fine fractions and were stored in well-labelled sample bags. For the picking procedures, fractions of the separated samples were examined individually on a picking tray. The tray was gridded to aid the picker and to ensure that the whole residues sprayed in the tray were thoroughly examined. All the available microfaunas (foraminifera) and other included macrofaunas regarded as accessories (gastropoda, ostracoda, pelycepoda and shell fragments) were picked from these samples with the aid of a picking brush viewed under a binocular microscope. The different occurring taxa (foraminifera and associated macrofaunas) recovered during the picking exercise were grouped into their respective genus and species, (where possible) and were mounted temporarily by the use of gum in the micropaleontological slide cavity. Micropaleontological cover slips were used in covering the slides to avoid spillage of the taxa and were arranged serially according to their depth in a slide tray for analysis. The following approach was employed in the sequence stratigraphic analysis and interpretation. However, the integration of biostratigraphic/ biofacies, paleobathymetric, lithologic attributes and wireline log datasets allowed for:

1. The identification and chronostratigraphic dating of all the key stratigraphic surfaces amongst; Transgressive Surface (TS), Sequence Boundary (SB) and Maximum Flooding Surface (MFS). The ability to recognize these key surfaces helps to unravel the stacking pattern thereby giving a clue in the understanding and interpretation of the sequence stratigraphic framework of the environment.

2. With the observed biostratigraphic/biofacies and wireline log motifs, all respective systems tracts were correctly delineated.

3. Depositional environments were defined using logs signatures and paleobathymetric datasets.

4. The sequence stratigraphic summary and foraminiferal distribution chart was generated using StrataBug and Corel software respectively.

The sequence stratigraphic analysis was carried out independently as a first step from biofacies and log datasets, and results were subsequently compared and integrated. Well logs interpretation involved detailed sub-division of the successions into the constituent parasequences and parasequences sets, from which lateral facies changes and the creation of accommodation space with changes in relative sea level were interpreted. These models therefore explain the exhibited types and distribution of reservoir sand bodies within the individual systems tracts which have been applied reliably in this interpretation.

Results and discussion

Foraminiferal biostratigraphic analysis of Well -'B':

Foraminiferal analysis of the ditch cutting samples obtained from well - 'B' (interval 1766 - 3974m) was carried out on one hundred and thirty-nine (139) samples. Out of this number, forty-three (43) ditch cutting samples were found to be barren of foraminifera. The analysed interval of the well with ninety-six (96) samples yielded rich and diverse microfauna with a total number of seventy-five (75) species identified and recorded from this well. However, calcareous foraminifera taxa predominated over their arenaceous counterparts while planktic taxa occurs sporadically within the top and lower sections of the well. The distributions of these species, as well as the stratigraphic interpretations are presented as Fig. 6 below. The integrated planktic schemes of Bolli and Saunders, 1985 (incorporating Blow, 1969) as well as known age diagnostic benthic assemblages in the Niger Delta were useful in attempting the zonation of the well (Fig. 7). Out of seventy-five (75) taxa occurrences, benthic foraminiferal taxa constituted sixty-three (63) species representing 84.0% of the total taxa recorded while twelve (12) species constituted the planktic species representing 16.0% of the total foraminiferal taxa encountered within this study well. In the benthic category, the calcareous foraminiferal taxa were found to be dominated with fifty-six (56) species representing 74.7% while the arenaceous foraminiferal taxa were left with seven (7) species which represent 9.3% (Figs. 8a and b). These groups of the foraminifera are also shown on the distribution chart of this well. Detailed biostratigraphic analysis indicates that well - 'B' (interval 1766 - 3974m) penetrated sediments of Late Eocene - Late Oligocene epoch for these sediments which were deposited in Non-marine to Upper bathyal paleo-water depths. Table 1 shows the digitized biostratigraphic summary chart of the Well - 'B' indicating all the events and encountered datum respectively.

Below are details of all the delineated foraminiferal zones in this study well:

The interval of the well, 1766 – 2180mis virtually barren of foraminifera taxa. The barren nature/non-occurrence of age diagnostic taxa did not allow for the age and zonation interpretations of the interval therefore the assignment of indeterminate status of the age.

The P22/N3 foraminiferal zone was found within the depth range of 2180 – 2590mand were deposited within the Late Oligocene age. This interval is characterized by the occurrences of FDO of *Chiloguembelina cubensis* at 2246m, single occurrence: *Glorobotalia opima nana* at 2510m and the Top Occurrence of *Eponides berthelotianus* at 2574m respectively. The upper part of this interval is barren of foraminifers, while the lower section shows sparse occurrences of benthic foraminifers with sandwiched planktic taxa counterparts. The foraminiferal benthic assemblage consists of *Hanzawaia strattoni, Nonionella auris, Hanzawaia concentrica, Florilus costiferum* and *Hopkinsina bononiensis*. Arenaceous benthic foraminiferal taxa such as *Ammobaculites strathearnensis, Spiroplectammina wrightii* and *Spiroplectammina biformis* were also recorded within this interval of the well. The boundary at the top of this well has not been encountered in this study due to the absence of diagnostic taxa such as *Globigerina angulioofficinalis* therefore, the top boundary of the well was not marked. However, the FDO of *Chiloguembelina cubensis* at 2246m which occurs within this interval of the well is known to occur within the Late Oligocene age (Bolli and Saunders, 198). The single occurrence of *Globorotalia opimanana* at 2510m (if in-situ) is indicative of the penetration of this microzone. The boundary was tentatively delineated at 2590m as no diagnostic foraminiferal taxon was encountered. The Maximum Flooding Surface (MFS) proposed at

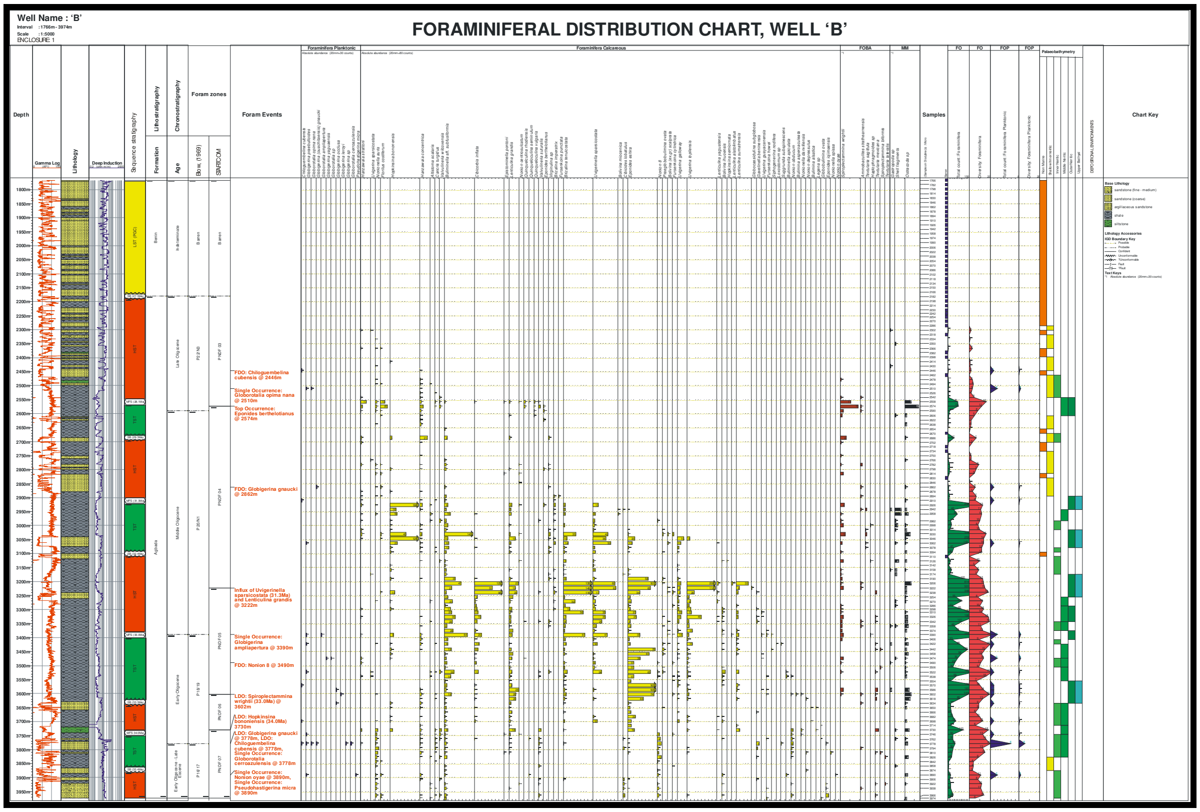

Figure 6. Foraminiferal distribution chart of well B.

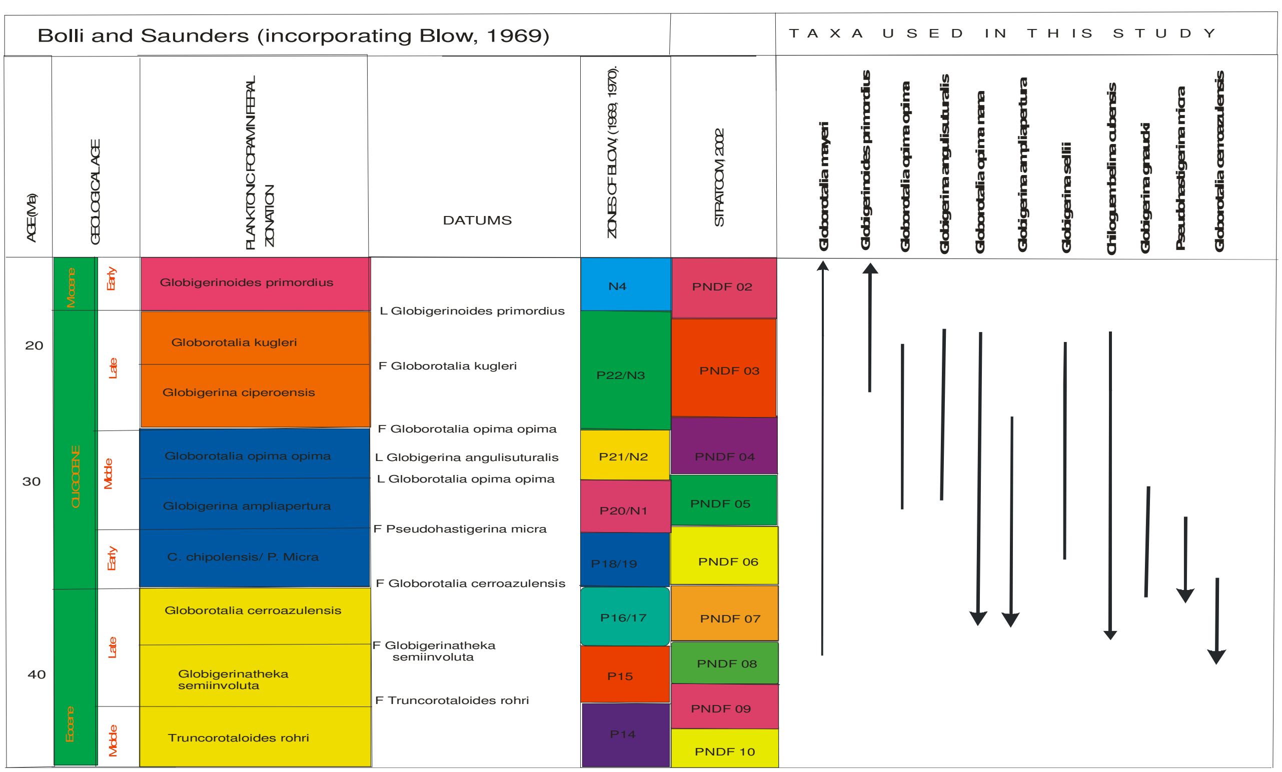

Figure 7. Key taxa used in foraminiferal zonation of well B.

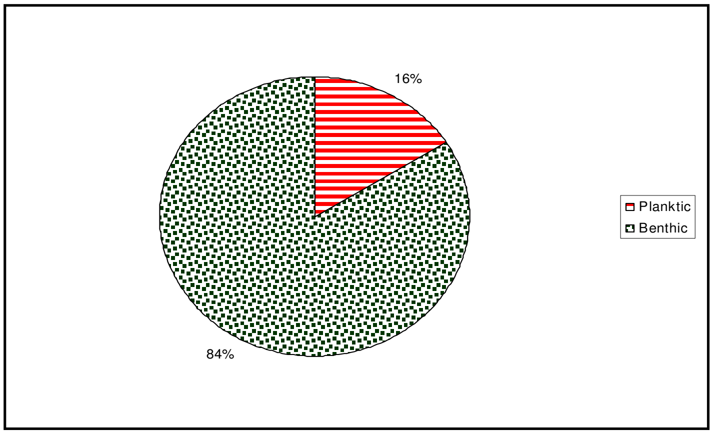

Fig. 8a. Foraminiferal distribution percentage chart of Well – 'B'.

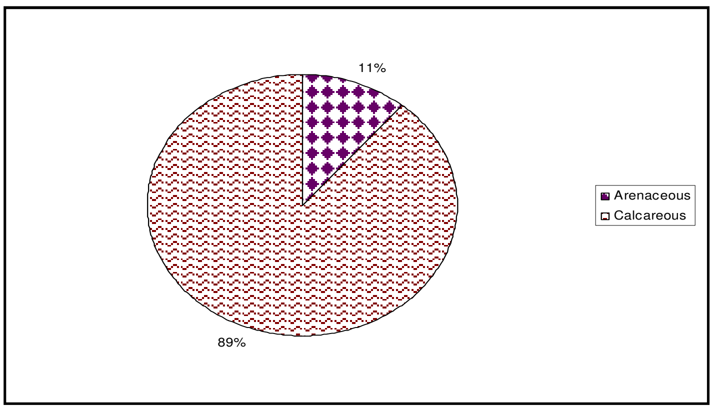

Fig. 8b. Benthic Foraminiferal percentage distribution chart for Well - 'B'.

2558m and dated 28.1Ma by calibration to the third order cycles of Haq et al., (1988) lends credence to the age interpretation of this interval.

The zone underlying the P22/N3 foraminiferal zone is the P21/N2 which occur at the interval depth of 2180 - 3390m. This zone is designated Middle Oligocene age. The occurrences of FDO of *Globigerina ouachitaenensis gnaucki* at 2862m, Influx of *Uvigerinella sparsicostata* (31.3Ma) and *Lenticulina grandis* at 3222m and a singular occurrence of *Globorotalia ampliapertura* at 3390m characterized this interval. This microzone is characterized by the occurrence of calcareous foraminiferal benthic taxa such as *Uvigerinella sparsicostata*, *Lenticulina grandis, Florilus costiferum, Uvigerina gawollayi, Hanzawaia strattoni, Nonionella auris, Eponides eshira, Brizalina tenuicostata* and *Hanzawaia concentrica*. Other calcareous foraminiferal benthic taxa such as *Quinqueloculina rhodiensis, Cibicorbis inflata, Uvigerina topilensis, Quinqueloculina vulgaris,* and *Valvulineriasuturalis* also occurred within this interval. However, *Hopkinsina bononiensis, Uvigerina topilensis* and *Buliminella aff. subfusiformis* occurrences were observed to be remarkable and persistent in this interval. Arenaceous foraminiferal benthic taxa such as *Textularia sagittula, Spiroplectammina wrightii* and *Ammobaculites strathearnensis* were observed within this interval.

The FDO of *Globigerina ouachitaenensis gnaucki* at 2862m and the single occurrence of *Globorotalia ampliapertura* at 3390m (if in-situ) is an indication of the penetration of the Middle Oligocene age as these taxa occur within this zone (Blow, 1969 and Bolli and Saunders, 1985). The base of this zone was delineated at 3390m as the FDO of *Globigerina tapuriensis* was not encountered in the analysed interval (Blow, 1969 and Bolli and Saunders, 1985).

The interval, 3390 - 3778m is assigned Early Oligocene in age and occurs within the P20/N1 foraminiferal zone. Taxa characterizing this zone include, single occurrence of *Globorotalia ampliapertura* at 3390m, FDO of *Nonion costiferum* at 3490m, LDO of *Spiroplectammina wrightii* at 3603m, LDO of *Hopkinsina bononiensis* at 3730m and LDO of *Globigerina ouachitaensis gnaucki* and single occurrence of *Globorotalia cerroazulensis cerroazulensis* at 3778m respectively. This foraminiferal zone is characterized by occurrences of *Spiroplectammina wrightii, Nonion costiferum, Hopkinsina bononiensis, Globigerina ouachitaenensis gnaucki* and *Globorotalia cerroazulensis cerroazulensis* within the interval. The preponderance

Table 1. Digitized Biostratigraphic summary chart of the Well - 'B'.

Interval (m)	Foram . Zone	Age	Events (Index taxa/Comment)
1766 2180	Barren	Inde ter- min ate	-Non-recovery of microfauna.
2180 2590	P22/N3	Late Oligocene	- FDO: *Chiloguembelina cubensis* at 2246m - 28.1Ma MFS at 2246m - Single: *Globorot*alia *opima nana* at 2510m - Top Occurrence: *Eponides berthelothianus* at 2574m
2590 3390	P20/N1	Middle Oligocene	- FDO: *Globigerina ouachitaenensis gnaucki* at2862m - Influx: *Spirolpectammina wrightii* and *Lenticulina grandis* at 3222m - 31.3Ma MFS at 3222m
3390 3730	P18/19	Early Oligocene	- Single Occurrence: *Globorotalia ampliapertura* at 3390m - FDO: *Nonion costiferum* at 3490m -LDO: *Spirolpectammina wrightii* at 3602m - 33.0Ma MFS at 3602m - LDO: *Hopkinsina bononiensis* at 3730m - 34.0Ma MFS at 3730m
3730 3974	P16/17	Early Oligocene - Late Eocene	- *LDO: Globigerina ouachitaenensis gnaucki* at 3778m - LDO: *Chiloguembelina cubensis* at 3778m - Single Occurrence: *Globorotalia cerroazulensis* at 3774m - Single Occurrence of *Nonion oyae* at 3890m - Single Occurrence of *Pseudohastigerina micra* at 3890m

(Note: FDO = First Downhole Occurrence and LDO = Last Downhole Occurrence. (Last Appearance Datum = First Downhole Occurrence and First Appearance Datum =Last Downhole Occurrence).

and associated calcareous foraminiferal benthic taxa within this zone include *Buliminella aff. subfusiformis, Brizalina imperatrix, Uvigerina topilensis, Lenticulina grandis, Hanzawaia concentrica, Eponides eshira, Nonionella auris, Lenticulina summatrensis, Uvigerina gallowayi* and *Praeglobobulimina ovata*. The persistent occurrence of *Eponides eshira, Uvigerinella sparsicostata, Cibicorbis inflata* and *Brizalina tenuicostata* are also remarkable in this interval of the well. Arenaceous benthic foraminferal taxa encountered within this interval are similar to that described in the preceding zone. The single occurrence of *Globorotalia ampliapertura* at 3390m (if in-situ) is indicative of the penetration of this microzone. However, the LDOs of *Spiroplectammina wrightii* (33.0Ma) at 3602m and *Hopkinsina bononiensis* (34.0Ma) at 3730m are important Niger Delta events associated with this chronostratigraphic surface. The base of this foraminiferal zone is tentatively delineated at 3778m based on the LDOs of *Globigerina ouachitaensis gnaucki* and *Globorotalia cerroazulensis cerroazulensis* at this depth. These bio-events occur within the P18/19 microzone of Stainforth et al., (1975).

Below the P20/N1 foraminiferal zone is the P18/19 – P16/17composite zone. This interval occurred within the depth interval of 3778 – 3974m and was observed to occur within the Early Oligocene - Late Eocene age. Diagnostic interval within this zone include occurrences of LDO of *Globigerina ouachitaensis gnaucki* at 3778m, LDO of *Chiloguembelina cubensis* at 3778m, single occurrence of *Globorotalia cerroazulensis* at 3778m and single occurrences of *Nonion oyae* and *Pseudohastigerina micra* at 3890m respectively. This microzone is characterized by occurrence of taxa such as *Globigerina ouachitaensis gnaucki, Chiloguembelina cubensis, Globorotalia cerroazulensis cerroazulensis, Nonion oyae* and *Pseudohastigerina micra*. Other calcareous benthic assemblagein association includes *Nonionellaauris, Hanzawaia concentrica, Bulliminella aff. subfusiformis, Lenticulina grandis, Eponides eshira, Bulimnella apiculata, Altistoma scalaris, Valuvlineria wilcoxensis, Globobulimina ovata, Nonion obducum, Bulimina alsatica, Gavelinella beninensis* and *Cibicides lobatulus*. Arenaceous benthic foraminiferal taxa within this zone are similar to that of the overlying faunal zone. The LDOs of *Globigerina ouachitaensis gnaucki* and *Chiloguembelina cubensis* at 3778m tentatively marks the top of this zone as these taxa occurred within this microzone. The single occurrence of *Globorotalia cerroazulensis cerroazulensis* at 3778 and *Nonionoyae* and *Pseudohastigerina micra* at 3890m (if in-situ) are indicative of the penetration of this zone.

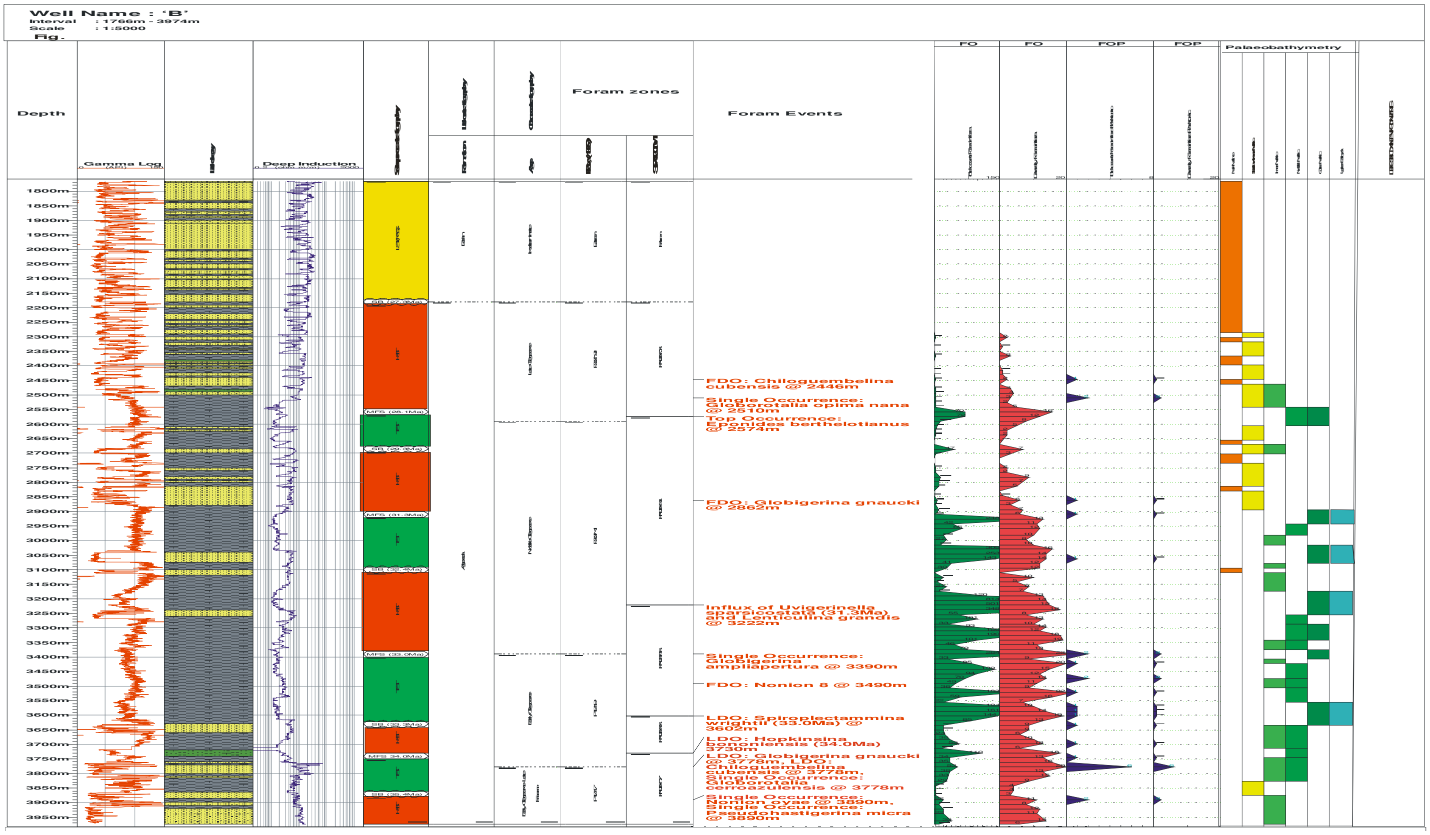

Figure 9. Stratigraphic summary chart of well B.

Globorotalia cerroazulensis and *Pseudohastigerina micra* is known to occur within the Late Eocene (P16/17) age according to Stainfort et al., (1975) while *Nonionoyae* is an endemic Eocene species in the Niger Delta (Petters, 1982). Thus the absence or non-occurrence of LDO of *Globigerina gortanii* taxon within this zone has hindered a boundary placement within this zone therefore this zone is considered as a composite (P18/19–P16/17) zone and dated Late Eocene – Early Oligocene age (Blow, 1969 and Bolli and Saunders, 1985). The base of this zone was probably not penetrated in the analyzed well of this study.

Sequence Stratigraphic Interpretation of well - 'B'

The integration of foraminiferal, observed sedimentological and wireline (Gamma ray and Deep Induction Resistivity) log datasets, allowed analysis/interpretation of the Sequence stratigraphic development within the analyzed interval of well - 'B' (interval 1766 -3974m) to be carried out. The approach of Emery and Myers, (1996) and Vail and Wornadt, (1991) was followed in attempting the sequence stratigraphic interpretation, while also taking into consideration the pitfalls commonly associated with log facies analysis, missing intervals as well as cave-ins. Four Maximum Flooding Surfaces (MFSs) have been delineated at 2558m, 2910m, 3390m and 3740m and dated 28.1Ma, 31.3Ma, 33.0Ma and 34.0Ma respectively. These candidate surfaces have been dated based on chronologically significant benthic and planktic foraminiferal bio-events as well as correlation to the third order cycles chart of Haq et al., (1988). The Maximum Flooding Surface (MFS) candidates were delineated on the basis of high foraminiferal abundance and diversity, coupled with high gamma ray and low Deep Induction Resistivity

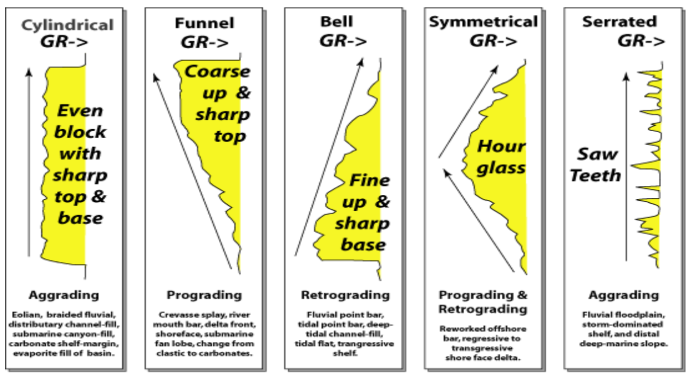

Figure 10a. Standard log motifs, gamma ray response to grain size variations (Modified from Emery and Myers, (1996).

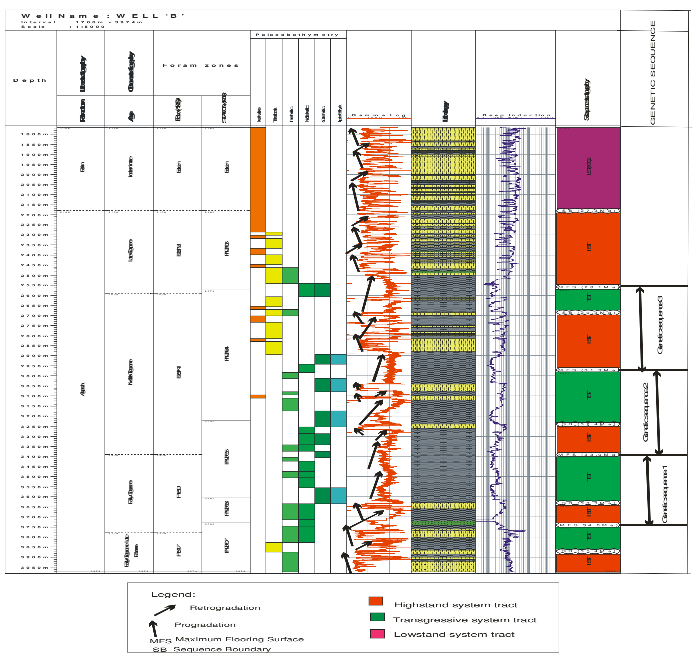

Figure 10b. Stacking pattern interpretation of well-B.

logs readings. Sequence Boundary (SB) candidates on the other hand, were recognized from abrupt kick to the right of the Deep Induction Resistivity log coupled with faunal minima and shallowing of paleo-water depths. The sediment stacking pattern of this well indicates the finning and coarsening upward sequences which equates with the standardized gamma ray response to variations in grain size (Figs. 10a). This is clearly shown by the log signatures (Gamma ray and Deep Induction Resistivity) and the described lithology of sediments which gives the stratigraphic position of this well. Dating of the key surfaces (MFS and SB) was achieved by correlation to the third order cycles chart of Haq et al., (1988) in association with chronostratigraphically significant benthic and planktic bio-events. The sequence stratigraphic summary of the analysed interval of the well is presented in Table 2 while three genetic sequences development has been recognized in this well (Fig 10b) adopting Galloway, (1989) genetic principle.

Table 2. Sequence Stratigraphic summary of well B.

Depth Interval (m)	Systems Tracts/ Key Surfaces
1766 – 2180	LST (PGC)
2180	SB (27.3Ma)
2180-2558	HST
2558	MFS (28.1Ma)
2558 - 2685	TST
2685	SB (29.3Ma)
2685 -2940	HST
2940	MFS (31.3Ma)
2940-3240	TST
3240	SB (32.4Ma)
3240 – 3390	HST
3390	MFS (33.0Ma)
3390 – 3630	TST
3630	SB (33.3Ma)
3630 – 3740	HST
3740	MFS (34.0Ma)
3740– 3870	TST
3870	SB (35.4Ma)
3870 – 3974	HST

Details of the sequence stratigraphic interpretations of well-'B' are presented below:

The onset of this highstand systems tract as shown on the distribution chart of well – 'B' was probably not

tested in this study at the Total Depth (TD) of the well and was observed within the interval depth of 3974 – 3870m (104m). This predominantly sand interval (with shale intercalations) was deposited in Inner Neritic paleo-water depth. This interval is characterized by progradational to blocky (coarsening upward) log signatures typical of a low sea level regime. The peak of regression (MRS) was delineated at 3870m, where a relatively low gamma ray and a high Deep Induction Resistivity log values are associated with the faunal minima. The sequence boundary (SB) encountered at the top this system tract is dated 35.4Ma by correlation to the third order cycles chart of Haq et al., (1988).

Underlying the Highstand systems tract is the Transgressive systems tract which occurs within the depth range of 3870 - 3740m (130m). These aggradational /retrogradational log motifs encountered in this interval are associated with predominantly shaly lithofacies deposited in Inner to Middle Neritic paleo-water depths. This phase of transgression culminated at the Maximum Flooding Surface delineated at 3730m based on the high gamma ray log value (low Deep Induction Resistivity log within the interval) associated with relatively high abundance and diversity of foraminifera at this depth. The encountered Maximum Flooding Surface (MFS) is dated 34.0Ma by correlation to the third order cycles chart of Haq et al., (1988). The LDO of *Hopkinsina bononiensis* at 3370m supports this interpretation as this bio-event is dated 34.0Ma in the Niger Delta.

The shales (hemi-pelagic – pelagic) and sands sediments encountered in this interval, 3740 - 3630m (110m)were predominantly deposited in Inner to Middle Neritic paleo-water depths and were observed to occur within the Highstand systems tracts. This shallowing upward sequence is associated with stacks of progradational log motifs; typical of regressive phase. The peak of this regressive phase (Maximum Regressive Surface- MRS) was delineated at 3630m based on the low gamma ray log value (high Deep Induction Resistivity log) associated with faunal minima at this depth. The Sequence boundary is dated 33.3Ma by correlation to the third order cycles chart of Haq et al., (1988).

The Transgressive systems tract at the interval depth of 3630 – 3390m (240m) were predominantly shale deposits (with minor sand intercalations) is associated with overall retogradational log pattern. This lithofacies were deposited in Outer Neritic – Upper bathyal water regime. This overall deepening sequence defines this transgressive phase, with its peak (MFS) delineated at 3390m, based on the relatively high Gamma ray and low Deep Induction Resistivity log values associated with a high abundance and diversity of microfauna at this depth. This is probably the equivalent of the *Spiroplectammina wrightii* Maximum Flooding Surface which is dated 33.0Ma by correlation to the third order cycles chart of Haq et al., (1988).

A renewed episode of deposition was witnessed at the depth interval of 3390 - 3240m (150m) which denotes the Highstand systems tract. The shales and sands lithofacies encountered in this interval were deposited in an overall shallowing upward depth of deposition within Outer through Middle to Inner Neritic paleo-water depths. Stacks of progradational log motifs as seen from the Gamma ray and Resistivity logs characterize the regressive phase which reached its peak (SB) at 3240m. The Sequence boundary was delineated based on the relatively low gamma ray and high Deep Induction log values associated with faunal minima at this depth. It is dated 32.4Ma by correlation to the third order cycles chart of Haq et al., (1988).

Below the highstand system tract is the Transgressive systems tract occurring at 3240 – 2970m (270m). These deposits were observed to have been deposited as stack sediments depicting retrogradational

(backstepping) log motifs associated with predominantly shaly lithofacies were deposited in the paleo-water depths that fluctuated between Non marine, Inner to Middle Neritic through Outer to Upper bathyal bathymetric realms. This overall deepening upward sequence defines this transgressive phase. The peak (MFS) of this phase was delineated at 2970m (log adjusted) based on the relatively high Gamma ray and low Deep Induction Resistivity log values at this depth. However, the high foraminiferal abundance and diversity associated with this surface is recorded at 2910m; this is attributed to the nature of the samples (ditch cuttings) used. This is the equivalent of the *Uvigerinella sparsicostata* Maximum Flooding Surface and it is dated 31.3Ma by correlation to the third order cycles chart of Haq et al., (1988).

Within the interval depth of 2970 – 2685m (285m), the highstand system tract was observed. Stacks of retrogradational /progradational parasequences characterize the lithofacies encountered in this interval. The lithofacies were deposited in the Middle to Inner Neritic through Non-marine paleo-water depths. The peak of progradation (MRS) was delineated at 2685m and is characterized by low Gamma ray and high Deep Induction Resistivity log values associated with faunal minima at this depth. It is dated 29.3Ma by correlation to the third order cycles chart of Haq et al., (1988).

The Transgressive system tract below the highstand system tract was deposited within the interval depth of 2685 – 2558m (127m). The overall retrogradational log signatures characterized the shale and sand lithofacies of this interval. The lithofacies were deposited in paleo-water depths that fluctuated between Non marineto Shallow-Inner through Middle to Outer Neritic bathymetric realms. The overall deepening upward sequence defines this transgressive phase, with its peak (MFS) delineated at 2558m, based on the relatively high Gamma ray and low Deep Induction Resistivity log values associated with high abundance and diversity of microfauna at this depth. This MFS is dated 28.1Ma by correlation to the third order cycles chart of Haq et al., (1988). The First Downhole Occurrence of *Chiloguembelina cubensis* at 2446m supports this interpretation. This bioevent is 28.1Ma in the Niger Delta province.

Stacks of progradational to blocky parasequences characterize the lithofacies (sand and shale) encountered at 2558 – 2180m (378m); and represent the Highstand systems tract. The lithofacies were deposited in Non-Marine to Inner Neritic paleo-water depths. The peak of progradation (SB) was delineated at 2180m and is characterized by low Gamma ray and high Deep Induction Resistivity log values associated with faunal minima at this depth. It is dated 27.3Ma by correlation to the third order cycles chart of Haq et al., (1988).

The most shoaling section of this well falls within the depth of 2180– 1766m (414m) and occurred within the Lowstand system tract (Prograding Wedge Complex). The sands and shale sediments encountered in this interval were deposited in predominantly Non-marine paleo-water depths. These lithofacies are associated with stacks of progradational and aggaradational log motifs (as observed on the corresponding high Gamma ray with Deep Induction Resistivity log signatures) probably depicting a Lowstand Prograding Wedge Complex. The peak of this regressive phase was probably not penetrated at the top depth; as a transgressive surface (TS); usually depicted by an abrupt shift of the gamma ray log to the right was not observed in the interval.

Sedimentological and Lithostratigraphic deductions of well - ’B’:

The sediments of well - ‘B’ penetrated the Benin Formation (interval 1766 – 2180m) as observed

apparently from the Deep Induction Resistivity log signatures that kicks to the right while the Agbada Formation (interval 2180 – 3974m) are made up of paralic development of sands and shales (with silt intercalations) as shown in the lithostratigraphic column (Table 3). Inference drawn from sediments of well – 'B' showed that the deposits are characterized by fine to coarse and sometimes pebbly grained sands, sandstones, shales and silt/siltstones intercalations. Table 3 below showed the lithostratigraphic penetration of this subsurface sediments while a summary of the major sedimentological unit identified in well – 'B' is also depicted in Fig. 7. However, based on the deduction presented on the table below, detailed discussions of the major litho-units encountered in this well are presented below.

Table 3. Lithostratigraphic interpretation of well B.

DEPTH (m)	LITHOLOGY	LITHOSTRATIGRAPHY
1766 - 2180	Predominantly sand /sandstone with intercalation of minor shales.	BENIN FORMATION
2180 - 2350	Predominantly sand and shale with sandstone intercalations.	AGBADA FORMATION
2350 - 2500	Predominantly sand and silt with shale interbeddings.	
2500 - 2800	Predominantly shale and sand intercalations.	
2800 - 3970	Predominantly shale/sand with silt intercalations.	

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The sediments found within the interval depth of 1766 – 2180m consist of sand/sandstone with silt intercalations. Sand deposits are the dominant lithology encountered within this interval. The sand is clean, colourless, fine to medium and sometimes coarse grained, subangular to subrounded, moderately to well sorted, calcareous, carbonaceous and slightly ferruginized.

Interbedding deposits which occur within the interval of 2180 - 2350m are sand/shale constituents. The sand body within this interval is as described for the overlying interval of the well. The shale is light to dark grey, subfissile to fissile, moderately hard to hard, micromicaceous, carbonaceous and sometimes ferruginized.

The interval depth of 2350 - 2500m consists of sand/silt with predominant sand occurrence. The sand is smoky white, medium to coarse, moderately sorted, subangular to subrounded calcareous slightly ferruginized. The silt is light grey, hard, carbonaceous and calcareous.

Within the interval depth of 2500 – 2800m, shale/sand intercalations were observed within the well. This interval is dominated by shale and sand with other minor sediments. The shale is light to dark grey, micromicaceous, carbonaceous and slightly ferruginized. The sand body encountered in this interval is as described in the overlying interval of this well.

At interval depth of 2800 - 3970m, shale/sand deposits were observed. The mentioned litho-unit consists principally of shale and sand intercalations with minor silt and sandstone occurrences. The shale which forms the predominant constituent within this interval is dark grey subfissile to fissile, moderately hard and sometimes fragile, micromicaceous, calcareous, carbonaceous and slightly ferruginized. Within this interval, coarse grained sand occurs mostly at the top and bottom. Generally, the grains are clean white, medium to coarse, moderately sorted, calcareous, subangular to subrounded, equant and sometimes slightly ferruginized. The silt is about one tenth of the total constituents in this interval. It is light grey, carbonaceous and calcareous. The sandstone is

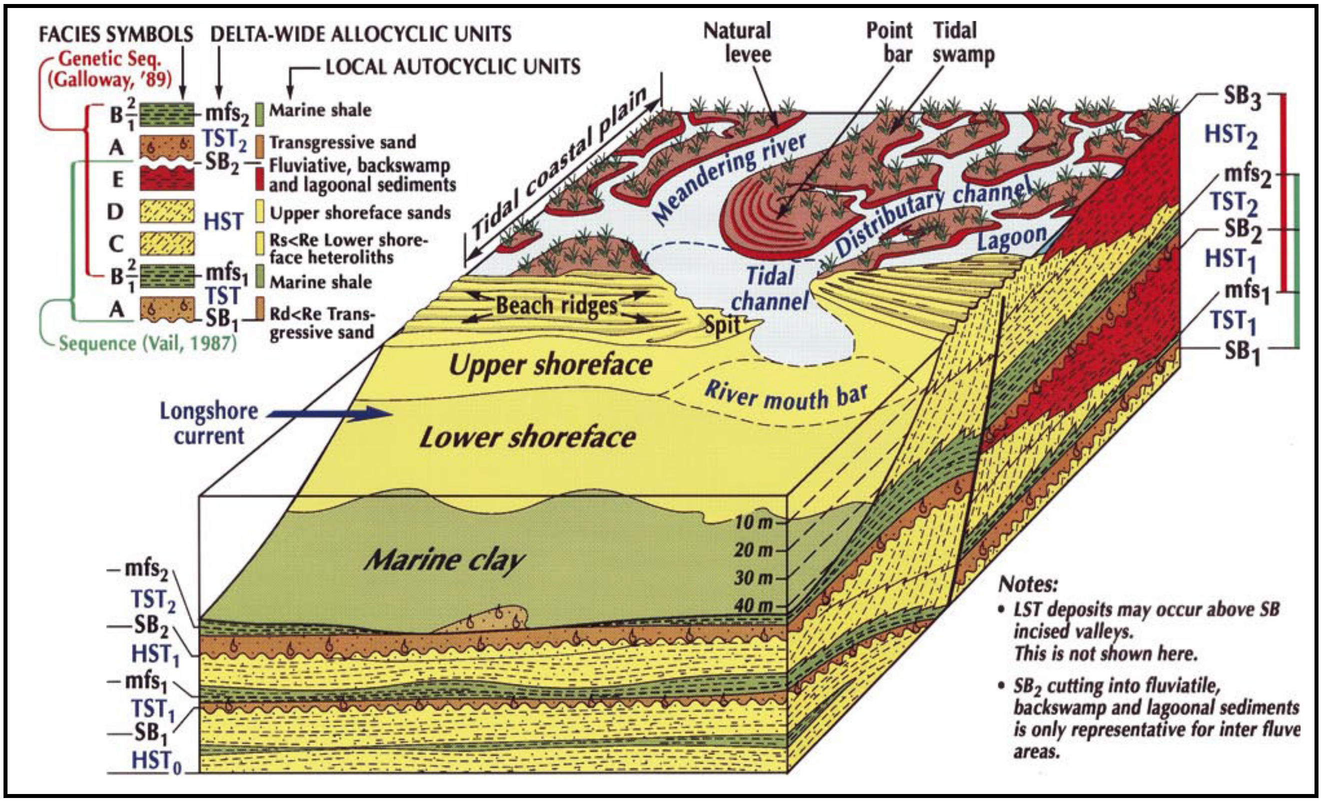

Figure 11a. Geomorphology, cyclic sedimentation and an active fault in the Tertiary Niger Delta (Modified after Weber, 1971).

light grey, fine grained, well sorted, slightly consolidated to moderately hard, calcareous, carbonaceous and slightly ferruginized. Calcareous debris and shell fragments also occurred as accessories.

Paleoenvironmental interpretation of well - 'B'

The integration of biostratigraphic, sedimentologic, lithologic and wireline (Gamma ray and Deep Induction Resistivity) log datasets was used to interpret the depositional environments of Well - 'B' (interval 1766 – 3974m). The paleoenvironmental interpretation concepts of Rider, (2006) and Weber, (1971) are adopted in this analysis in a view to recognizing all the sub-environments within the Niger Delta (Fig. 11a & 11b). However, each of the depositional environments encountered in this well is therefore compared with standard sedimentological log motifs (Fig. 11b). The relative abundance and diversity of the recovered foraminifera as well as the occurrences of environmentally significant foraminiferal benthic taxa were utilized in the estimation of the depositional environment of these sediments. The results based on foraminiferal biofacies analysis indicate that the sediments encountered in the analysed interval of well - 'B' were deposited in Non-marine – Upper bathyal water paleo-depths. The depositional environments and logs motifs pattern denoting all the encountered depositional settings in well-'B' are shown in Fig. 12 and Fig. 13 respectively. However, Fig. 14 highlighted the bathymetric ranges that are used for this interpretation bearing in mind the ranges of the foraminiferal taxa occurrences. Table 4 shows a digitized depositional pattern of the well section

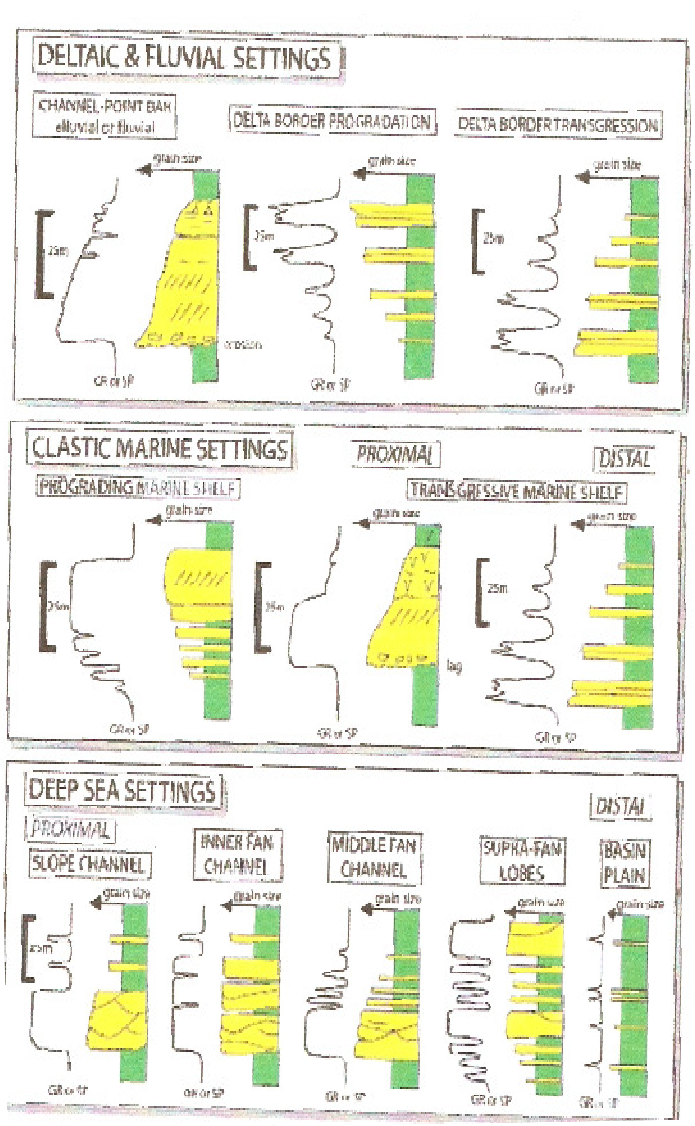

Figure 11b. Standard sedimentological log motifs and depositional settings (Modified after Rider, 2006).

derived from the depositional environments, stacking pattern of the log motifs and foraminiferal biofacies.

The paleobathymetry interpretation adopted in this study is in lined with the depth range as denoted on figure 15 above.

The paleoenvironmental interpretation observed within the interval depth of 1766 – 2286m (520m) showed that the bathymetric settings depicted a Non-marine realm [0 – 0.5m] while the sediments were deposited within a tidal channel environment. This interval of the study well is made up of intercalations of medium to very coarse grained sands and with minor siltstone. The log signature witnessed within this well is progradational/blocky and depicts their deposition probably as tidal channel deposits in a delta plain setting. Minor gastropoda, shell fragments occurred with abundant coal materials as accessories within this interval.

Within the depth of 2286 – 2446m (160m), the paleobathymetric realm was observed to occur within the Non-marine – Shallow Inner Neritic setting [0 – 1.0m]. The depositional environment was found to occur within the distributary mouth bar setting. The log motifs characterizing this medium to coarse sand are stacks of aggradational/progradational signatures which depicts their deposition as distributary mouth bar sediments. This lithofacies which exhibits a coarsening upward trend is a suggestive of distributary mouth bar deposits in a delta front setting. The lower part (2380 – 2446m) of this interval shows sandwiched/sparse occurrences of benthic taxa such as *Hopkinsina bononiensis*, *Uvigerina sparsicostata*, *Florilus costiferum, Hanzawaia strattoni,* and *Nonionella auris*. This interval was probably deposited in a Non-Marine to Shallow Inner setting with minor marine influence.

This channel fill/bar complexes depositional environments showed a bathymetric setting ranging from Shallow Inner - Inner Neritic [1.0 – 20m] within the depth interval of 2446 - 2558m (112m). The interval is predominantly made up of shale lithofacies with intercalations of sand and silt. These are characterized by progradational/retrogradational log patterns suggesting their deposition as channel fill/bar complexes facies in a delta front setting. Foraminiferal taxa associated with this interval include *Ammobaculites strathearnensis*, *Spiroplectammina wrightii, Nonionella auris* and *Florilus costiferum.*

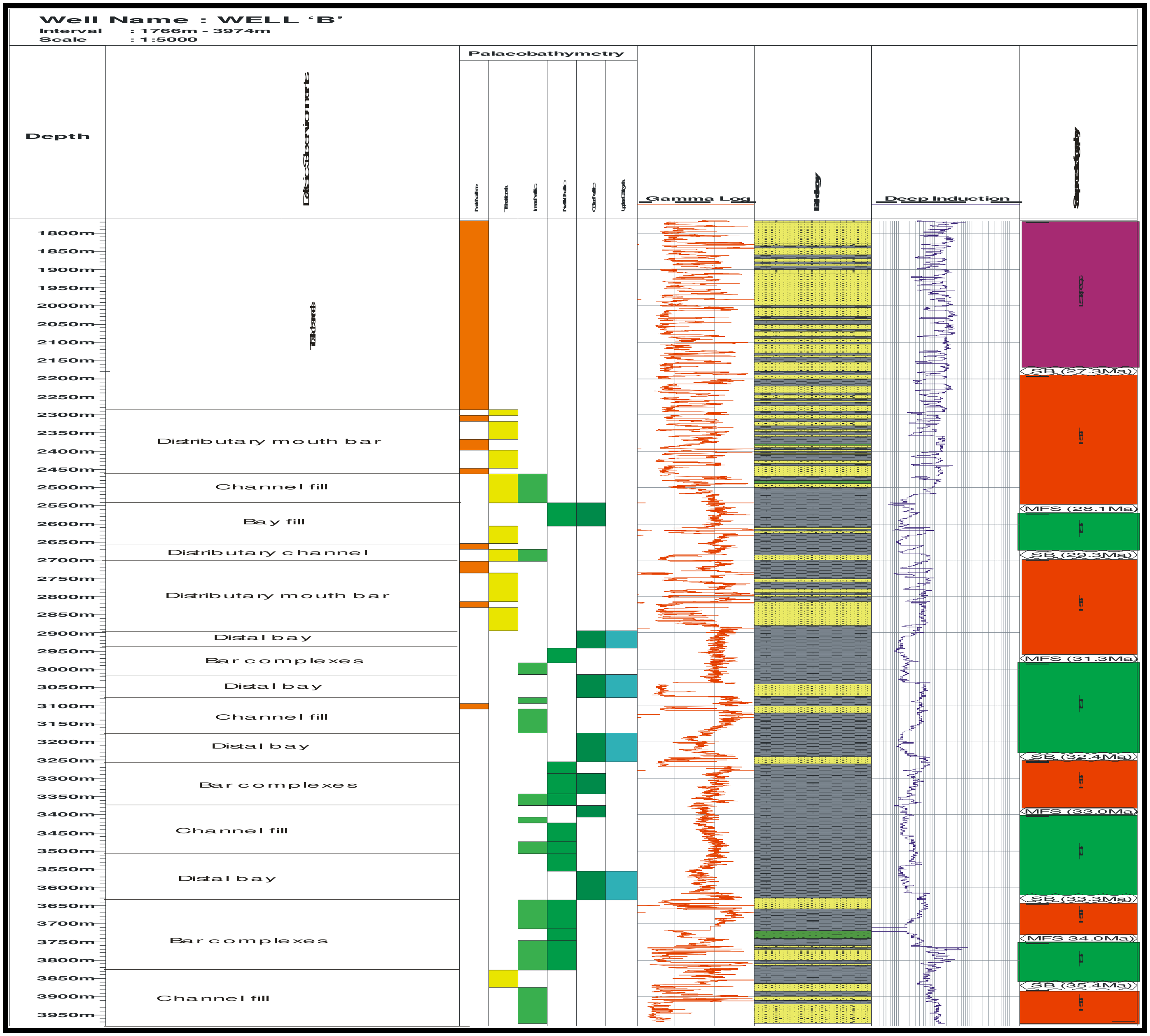

Figure 12. Depositional environments of well B.

The sediments within the depth range of 2558 - 2654m (96m) were observed to be deposited within the paleobathymetric realms of Middle – Outer Neritic [20 – 60m]. The environments of deposition consist of bay fill/bar complexes. The log motifs characterizing this shale and sand interval are stacks of retorgradational/progradational signatures which depicts their deposition as bay fill/bar complexes sediments. This lithofacies which exhibits a fining upward trend or sequence is a suggestive of bay deposits in prodelta – open shelf setting. The faunal assemblage in this interval is made up of *Hanzawaia strattoni*, *Quinqueloculina vulgaris*, *Brizalina imperatrix*, *Hanzawaia concentrica*, *Nonionella auris*, *Cancristurgidus*, *Lenticulina grandis* and *Valvulineria wilcoxensis*. A persistent occurrence of *Spiroplectammina wrightii* taxon was remarkable within this interval. A shoaling in paleo-water depths

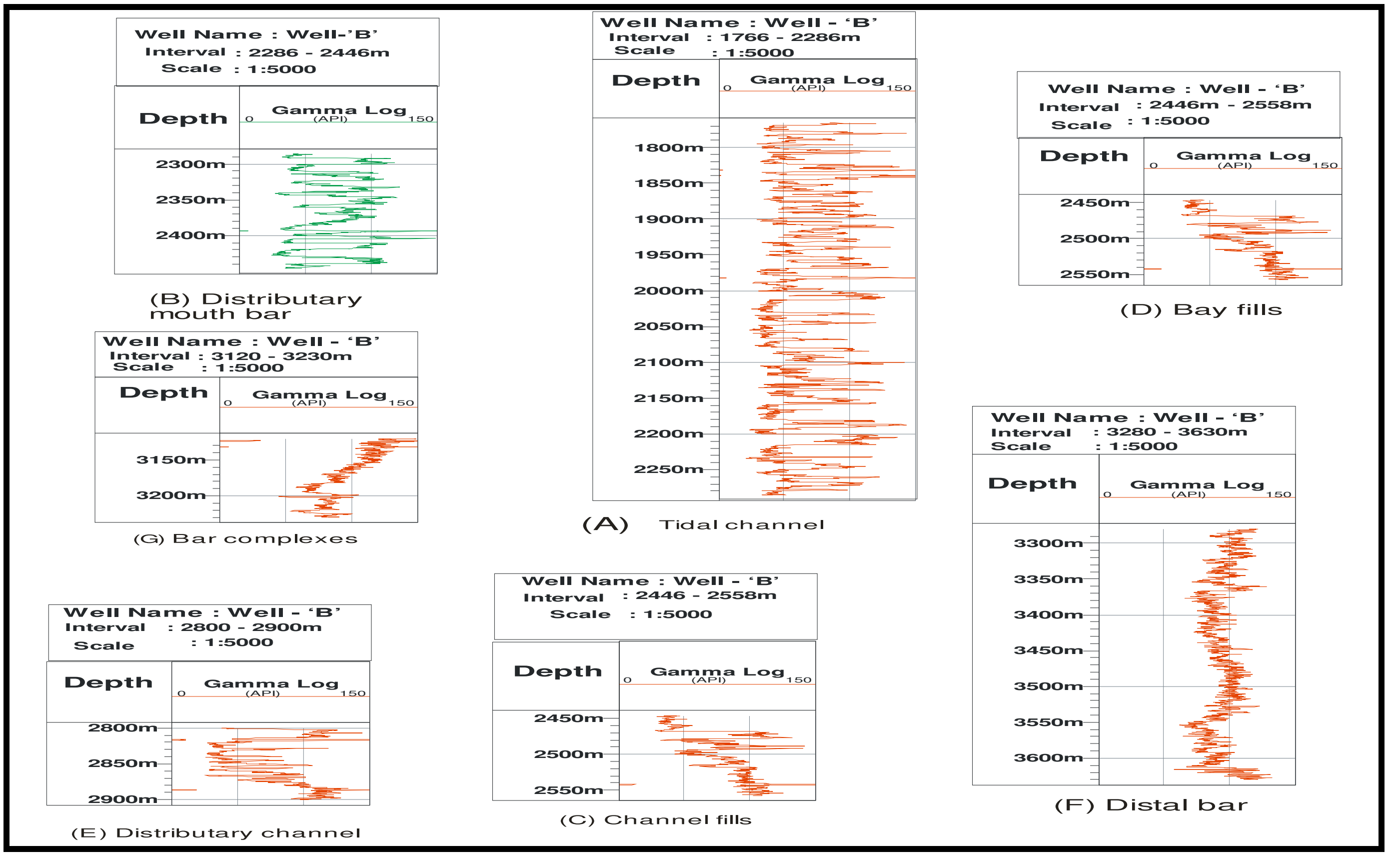

Figure 13. Log pattern denoting depositional settings in well B.

to Shallow-Inner Neritic is observed within the base of this interval (2606 – 2654m) where a drop in abundance and diversity of foraminiferal taxa were observed.

The interval depth of 2654- 2702m (48m) witnessed a deposition within the distributary channel environment while the bathymetric setting ranges from Shallow-Inner – Inner Neritic [1.0 – 20m]. Wireline signatures and lithologic description of the sediments within this interval indicate a predominantly retorgradational shales and progradational, medium to coarse grained sand and sandstone, suggestive of distributary channel fills. This environment of deposition fluctuated between Shallow-Inner and Inner Neritic realm based on the few benthic foraminiferal taxa encountered in this interval such as *Hanzawaia concentirca, Buliminella aff. subfusiformis, Virginulina* sp. and *Eponides berthelotianus*. Minor shell fragments and ostracoda species are present as accessories.

The sediments found within the depth of 2702 - 2894m (192m) were deposited within the distributary channel environment in a Non-marine - Shallow-Inner Neritic [0 – 1.0m] paleo-water depths. This litho-unit consists predominantly of shales with sands intercalations which are characterized by progradational/retrogradational log signatures. The medium to coarse grained sand within this interval suggests deposition as distributary channel facies within the delta plain – delta front setting. The upper section of this interval are completely barren of foraminifers while the lower section shows sparse occurrences of *Hopkinsina bononiensis, Floriluscostiferum, Nonionella auris, Hanzawaia strattoni, Textularia sagittula* and *Spiroplectammina wrightii.*

Table 4. Paleoenvironmental deduction of well B.

Depth (m)	Depositional Environment	Log Pattern	Paleobathymetry
1766- 2286	Tidal channel	Progradational/ Aggradational	NM
2286- 2446	Distributary mouth bar	Progradational/ Aggradational	NM – SH. IN
2446- 2558	Channel fill	Progradational/ Retrogradational	SH. IN – IN
2558- 2654	Bay fill	Retrogradational	MN – ON
2654- 2702	Distributary channel	Progradational/ Retrogradational	SH. IN – IN
2702- 2894	Distributary mouth bar	Progradational/ Retrogradational	NM – SH. IN
2894- 2942	Distal bar	Retrogradational	ON – UB
2942- 3014	Bar complexes	Retrogradational	IN – MN
3014- 3078	Distal bar	Progradational/ Retrogradational	ON – UB
3078- 3174	Channel fill	Progradational/ Retrogradational	IN
3174- 3254	Distal bar	Progradational/ Retrogradational	ON – UB
3254- 3390	Bar complexes	Retrogradational	MN – ON
3390- 3554	Channel fill	Progradational/ Retrogradational	IN – MN
3554- 3634	Distal bar	Retrogradational	ON – UB
3634 - 3826	Bar complexes	Progradational/ Retrogradational	IN – MN
3826- 3974	Channel fill	Progradational/ Retrogradational	SH – IN

The depth interval of 2894 - 2942m (48m) records a high abundance and diversity of foraminifers and ranges from Outer Neritic – Upper Bathyal [100 – 250m] paleo water depths. The encountered depositional environment is mainly distal bar setting. Calcareous benthic taxa predominate over other foraminiferal counter-parts. The abundant and persistent occurrences of *Hopkinsina bononiensis, Spiroplectammina wrightii, Floriluscostiferum* and *Hanzawaia concentrica* characterized this interval. Also, the persistent occurrences of *Lenticulina grandis, Quinqueloculina seminulum, Quinqueloculina vulgaris, Quinqueloculina rhodiensis* and *Ammobaculites strathearnensis* are significant within this interval. The shales and minor silts sediments encountered in this interval were deposited within a distal bay in an open shelf setting depicting a retrogradational log motifs pattern.

Sediments deposited within the interval of 2942 - 3014m (72m) were observed to exhibit retrogradational/progradational log pattern. These sediments were depositedin an Inner – Middle Neritic [1.0 -100m] paleobathymtric realm. Bar complexes characterizes the environment of deposition encountered within this interval. However, this interval is predominantly made up of shales with silts intercalations whose log signatures is fining upward trend in nature, depicting their deposition as bar complexes in delta front settings. Faunal assemblage characterizing this interval includes increase in

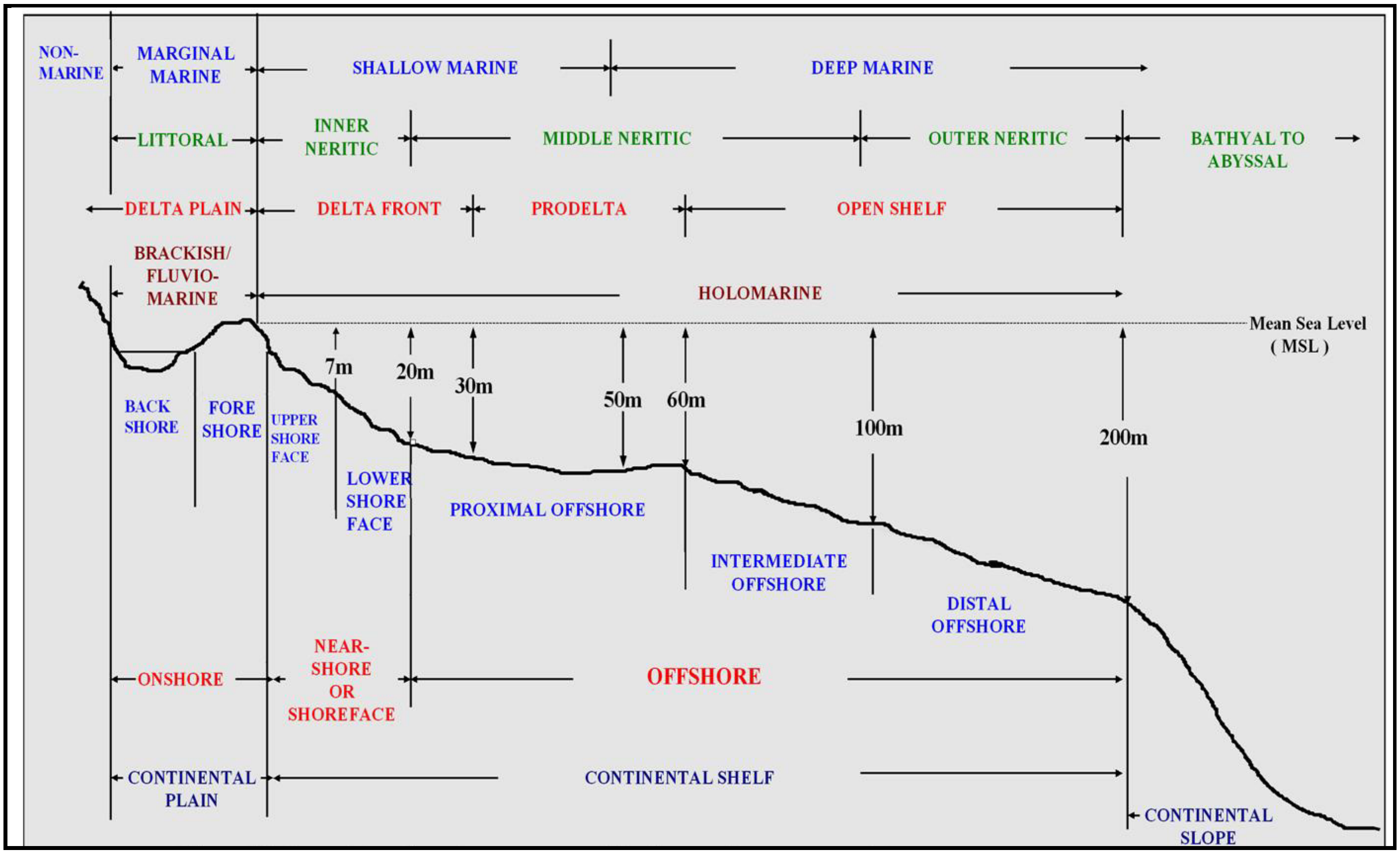

Figure 14. Depositional environments and bathymetric ranges used in paleoenvironmental interpretations (Modified after Allen, 1965 & 1970).

abundance and diversity of *Uvigerinella sparsicostata, Brizalina tenuicostata, Eponides eshira, Brizalina imperatrix, Hopkinsina bononiensis, Buliminella aff. subfusiformis, Lenticulina grandis* and *Hanzawaia concentrica*. This interval which witnessed a shoaling paleo-water depth to Inner shelf setting is observed towards the base of this interval as shown by the sparse occurrence of foraminiferal taxa. This interval shows minor occurrences of gastropoda, ostracoda and shell fragments as accessories.

The depositional environment encountered this interval, 3014 - 3078m (64m) depicted a distal bar setting with bathymetric realm ranging from Outer Neritic – Upper Bathyal [100 – 250m] paleo water depths. The log signatures showed a retrogradational /progradational pattern as such the deepening in paleo-water to predominantly upper bathyal realm setting is characterized by an increase in abundance and diversity of microfauna within this interval. In addition to the taxa listed in the preceding interval are the occurrences of *Globigerina praebulloides praebulloides, Virginulina* sp, *Uvigerina topilensis, Hanzawaia strattoni, Textularia sagitula* and *Spiroplectammina wrightii*. Lithologically, this interval consists of predominantly shales and sands which are characterized by fining upward/coarsening upward log motifs suggesting their deposition as distal bay in a predominantly open shelf setting. Accessory within this interval is similar to the overlying interval.

Wireline log signatures and lithologic description of the sediments within this interval, 3078 - 3174m (96m) indicate a predominantly retrogradational /progradational sequence of shales with interbeds of sand, minor silt and sandstone suggestive of

channel/bay fill deposits. The sediments were deposited predominantly in the Inner Neritic [1.0 – 20m] paleo water realm. Gastropoda and shell fragments occurred as accessories. The environment of deposition is fluctuated between Non-marine and Inner Neritic paleo-water depths as observed from the decrease in abundance and diversity of the faunal assemblage which include *Brizalina imperatrix, Cibicides lobatulus, Brizalina tenuicostata,* and *Epistominellapontoni*. A shoaling to Non-marine setting is observed at the mid-section (3110m) of this interval. This fluctuation may be as a result of facies changes within this interval of the well.

The shale streaks of sand and minor silt found within the interval depth of 3174 - 3254m (80m)is characterized by fining upward and coarsening upward (retrogradational /progradational) log signatures suggesting distal bay deposits in prodelta setting. The encountered paleo water depths ranges from Outer Neritic – Upper Bathyal [100 – 250m] settings. These sediments were within the distal bar environment. Unidentifiable ostracoda and shell fragments were recorded as accessories. The foraminiferal content within this interval consists of *Lenticulina sumatrensis, Lentculina yaguatensis, Fusenkoina howei, Praeglobobulimina ovata, Altistoma sclaris* and *Fusenkoina cylindrica*. This interval showed preponderance and persistent occurrences of *Hopkinsina bononiensis, Buliminella aff. subfusiformis, Hopkinsina* sp, *Brizalina tenuicostata, Epoindes eshira, Uvigerinella sparsicostata* and *Uvigerina topilensis*. However, this interval witnessed an overall deepening of paleo-water depth as observed by the abundance and diversity of foraminifers within this interval.

This litho-units encountered within the depth interval of 3254 - 3390m (136m)are predominantly shales and minor silts intercalations. The paleobathymetric interpretation of this interval points to the Middle - Outer Neritic [20 – 200m] paleo water realm while the depositional environment suggested bar complexes. The log signatures are characterized by fining upward trend associated with retrogradational facies. This deposition depicts as bar complexes within a delta front to prodeltaic setting. The foraminiferal assemblage within this interval is similar to that of the preceding interval though a minor decreased in fauna content were observed. However, this shoaling of paleo-water depths observed towards the mid-section of this interval has drastically decreased the foraminiferal occurrences and was followed by another episode of deepening of environment to Outer Neritic realm as a result of increase in abundant and diversity of taxa towards the base of this interval.

These litho-units observed within this interval depth of 3390 - 3554m (164m) are predominantly shales deposits with a retrogradational log pattern. The paleo water depth suggests a deposition found within the Inner - Middle Neritic [1.0 – 100m] settings. The log motifs are characterized by fining upward trend within this interval which suggests deposition admixture channel fills/bar complexes facies within a delta front to prodeltaic setting. The associated microfaunal taxa within this interval include *Uvigerina topilensis, Brizalina imperatrix, Lenticulina grandis, Cibicorbis inflata, Hanzawaia concentric* and *Nonionella auris*. The occurrence of planktic taxa within this interval was remarkable, they include, *Globigerina praebulloides praebulloides, Globorotalia ampliapertura, Globigerina praebulloides leroyi* and *Globigerina praebulloides occulsa*.

Wireline log signatures and lithologic description of sediments within the interval depth of 3554 - 3634m (80m) are predominantly retrogradational shales and a minor progradational, medium to coarse grained sands with interbeds of silts, suggestive of distal bay deposits. The paleobathymetric setting ranges from Outer Neritic – Upper Bathyal [100 – 250m] realm.

Increase in occurrence of unidentifiable ostracoda species and shell fragments were recorded as accessories. The occurrence of *Uvigerina topilensis, Uvigerinella sparsicostata, Bulimina alsatica, Fursenkoina howei, Nonion obducum, Lenticulina sumatrensis, Ammobaculites strathearensis* and *Haplophagmoidessp* were recorded within this interval of the well. The persistent occurrences of *Eponides eshira, Buliminella aff. subfusiformis, Cibicorbis inflata,* and *Brizalina tenuicostata* were significant within this interval. This interval witnessed an overall deepening paleo-water depths setting as observed from the abundance and diversity of microfaunal content within this interval.

This litho-units observed within the interval, 3634 - 3826m (192m) consist of predominantly shales with minor coarse grained sand and silts towards the base of this interval. The sediments were predominantly deposited in a Middle Neritic [20 - 100m] paleo water depth. The log signatures are characterized by coarsening and sometimes fining upward trend which suggests a deposition as channel fill/bar complexes facies within a delta front to prodeltaic settings. The faunal assemblage observed within this interval is made up of *Vuluvlineria suturalis, Hanzawaia concentrica, Cancris turgidus, Nonionella auris, Uvigerina guayacanensis, Lenticulina sumatrensis, Galvelinella beninensis, Nonion obducum* and *Vulvulineria wilcoxensis*. Planktic taxa such as *Globigerina praebulloides praebulloides, Globorotalia cerroazulensis* and *Globigerina* sp. were recorded within this interval. The depositional pattern progrades steadily but with a slight decrease in abundant and diversity of the foraminiferal taxa towards the base of this interval.

Channel fills depositional environments were observed for sediment found within the interval depth of 3826 - 3974m (148m). The sediments were interpreted to have been deposited in the Shallow Inner – Inner Neritic [0 – 1.0m] bathymetric realm. The litho-units observed within this interval consist of predominantly shales with intercalations of medium to coarse grained sands and sandstones. These litho-units were probably deposited as channel fill units with fining upward trend at the top while the base showed coarsening upward deposits within a delta front to prodeltaic settings. Shell fragments, gastropoda and ostracoda were recorded as accessories. This Shallow – Inner Neritic water realm is characterized by the occurrence of foraminiferal taxa such as *Cibicides lobatulus, Globobulimina ovata, Nonion* sp.*, Floriluscostiferum, Hanzawaia strattoni* and *Altistomascalaris*. A slight shoaling of paleo-water depths to Shallow – Inner Neritic is observed within the upper section (3826 – 3874m) of this interval; while a deepening setting to probably Inner Neritic water realm is witnessed in the interval between 3874 – 3974m.

Conclusion

The biostratigraphic/biofacies analysis, wireline log data sets, and lithologic descriptions of the subsurface sediments of well-'B' in this study reveal the penetration of Benin and Agbada Formations respectively. Sediments which penetrated by the Benin Formation were observed apparently from the Deep Induction Resistivity log signatures that kicks to the right while the Agbada Formation deposits were made up of the paralic development of sands and shales (with silt intercalations). Taxonomically, calcareous foraminiferal taxa predominate over their arenaceous counterparts while planktic taxa were found to be more or less sporadically present within the analyzed intervals of the well. Known and used planktics and benthic zonation schemes were consulted and accordingly used which lends credence to the interpretation of the designated zones and ages delineated in all the analysed wells. Age interpretations and the definition of foraminiferal

zones were achieved using the First and Last Downhole Occurrences (FDO and LDO) of age diagnostic planktic taxa as well as known age diagnostic benthic assemblage(s) in the Niger Delta. This allows the designation of the Late Eocene – Late Oligocene age (P16/17 – P22/N3) and permit identification of their principal horizons. These horizons were used to arrive at the subdivisions and interpretation of these deposits in relation to tectonic, eustatic, and active dynamic processes during the deposition of those units. This well in the vertical successions is composed of the following elements in this order; Lowstand systems tract (LST), Sequence Boundary (SB), Highstand systems tract (HST), Maximum Flooding Surface (MFS) and Transgressive systems tract (TST). However, these sequences show local important variations in thickness and facies. Sequence stratigraphic analyses of well-'B' resulted in the identification of four Maximum Flooding Surfaces (MFSs) at 2558m (28.1Ma), 2940m (31.3Ma), 3390m (33.0Ma) and 3740m (34.0Ma) while the associated Sequence Boundaries (SBs) were encountered at 2180m (27.3Ma), 2685m (29.3Ma), 3240m (32.4Ma), 3630m (33.3Ma) and 3870m (35.4Ma). Apparently, the dating of these key surfaces was achieved by correlation to the third order cycles chart of Haq et al., (1988) as well as inferences from chronostratigraphically significant bioevents. The paleoenvironmental interpretations of the study well were based on the integration of the microfaunal, paleobathymetric, lithologic description and wireline (Gamma ray and Deep Induction Resistivity) log datasets. However, the results of the paleobathymetric delineation showed that the stratigraphic development of the well - 'B' took place in delta plain to prodelta through open shelf setting, deposited within Non - marine to Upper bathyal; well - 'D', Non-marine to Outer Neritic. Therefore, the overall result indicates that the stratigraphic development of well-'B' in this study took place within the delta plain to open shelf paleoenvironments within Non-marine to Upper bathyal paleo-water depths.

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References

Adegbenga, O., Dorobek, S. L., Jensen, J. L., & Wills, B. J. (2003). High resolution sequence stratigraphic and reservoir characterization studies of D-07, D-08 and E-01 sands, block 2 Meren field, offshore Niger delta (abs.): *American Association of Petroleum Geologists Bulletin*. Abstracts with Programs, 87, A50.

Adeogba, A. A., McHargue, R. T., & Graham, S. A. (2005). Transient fan architecture and depositional controls from near-surface 3-D seismic data, Niger Delta continental slope. *American Association of Petroleum Geologists Bulletin*. 89(5), 627 – 643.

Adeigbe, O. C., Oduneye, O. C., Yussuph, I. A., Okpoli, C. C. (2012). Late Miocene- Pleistocene Foraminiferal Biostratigraphy of Well Eb-1 and Eb-2 Offshore Depobelt, Western Niger Delta, Nigeria. *International Journal of Applied Sciences and Engineering Research*, 2(3), 382-397.

Adeniran, B. V. (1997). Quantitative Neogene Planktic foraminiferal biostratigraphy of Western Niger Delta. *Nigerian Association of Petroleum Explorationists Bulletin*. 12(1), 54 – 69.

Allen, J. R. L. (1965). Late Quaternary Niger Delta and adjacent sedimentary environments and lithofacies. *American Association of Petroleum Geologists Bulletin*. 49: 547 – 600.

Allen, J. R. L. (1970). Sediments of the Modern Niger Delta, a summary and review. In: J. P. Morgan and R. H. Shaver (eds.); Deltaic Sedimentation, Modern and Ancient. *Gulf Coast Section Society of Economic Paleontologists and Mineralogists*. 15, 138 – 151.

Armentrout, J. M., & Clement, J. F. (1990). Biostratigraphic correlation of depositional cycles; a case study of High Island Galveston – East Breaks areas, Offshore Texas. In: Sequence stratigraphy as an Exploration tool: Concepts and practices in the Gulf Coast. *Gulf Coast Section Society of Economic Paleontologists and Mineralogists,* Eleventh Annual Research Conference Program and Abstracts. 21 – 51.

Armentrout, J. M., Echols, R. J., & Lee, T. D. (1990). Patterns of Foraminiferal abundance and diversity: Implications for Sequence Stratigraphic analysis. . In: Sequence stratigraphy as an Exploration tool: Concepts and practices in the Gulf Coast. *Gulf Coast Section Society of Economic Paleontologists and Mineralogists*. Eleventh Annual Research Conference Program and Abstracts. 51 - 85.

Armitage, D. A., McHargue, T., Fildani, A, & Graham, S. A. (2012). Postavulsion channel evolution: Niger Delta continental slope. *American Association of Petroleum Geologists Bulletin*. 96(5), 823 – 843.

Armstrong, H. A., & Brasier, M. D. (2005). Microfossils: Second edition, Blackwell Publishing Ltd., United Kingdom, 1 – 296.

Asseez, L. O. (1976). Review of the Stratigraphy, Sedimentation and Structure of the Niger Delta. In: Kogbe, C. A (ed.), Geology of Nigeria; Elizabeth Publishing Company. Lagos, Nigeria. 259 – 272.

Augustina, E., Osegbo, U., Jacob, M., & Adebambo, (2008). Paleoecological reconstruction of Nigerian Deep Water well using Foraminiferal Morphogroup analysis. Nigerian Association of Petroleum Explorationists, extended abstracts, PA2.

Avbovbo, A. A. (1978). Tertiary Lithostratigraphy of the Niger Delta. *American Association of Petroleum Geologists Bulletin*. 62(2), 295 – 306.

Balogun, A. O. (2003). Sequence Stratigraphy of "X" Field in the Coastal Swamp Depobelt of the Niger Delta, Nigeria. *American Association of Petroleum Geologists Bulletin*, International Conference Barcelona, Spain. 236 - 242.

Beka, F. T., & Oti, M. N. (1995). The distal Offshore Niger Delta: Frontier prospects of a mature Petroleum province. In: M. N. Oti and G. Postma (eds.), Geology of Deltas. Belkema Publishers. 237 – 241.

Benkhelil, J. (1987). The Origin and evolution of Cretaceous Benue Trough, Nigeria. *Journal of African Earth Science*. 8, 251 – 282.

Blow, W. H. (1969). Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy. In: Bronnimann, P. and Renz, H. H. (eds). Proceedings First International Conference on Planktonic Microfossils. Geneva, 1: 199 – 421.

Boboye, O. A., & Adeleye, A. M. (2009). High Resolution Biostratigraphy of Early Pliocene – Late Miocene Calcareous Nannoplankton and Foraminiferal, Deep offshore, Niger Delta, Nigeria. *European Journal of Scientific Research*. 34(3), 308-325.

Bolli, H. M., & Saunders, J. B. (1985). Oligocene to Holocene low latitude planktic foraminifera. In: H. M. Bolli, J. B. Saunders and K. Perch – Nielsen, (eds.), Planktic Stratigraphy. Cambridge University Press. 155 – 257.

Bustin, R. M. (1988). Sedimentology and characteristics of dispersed organic matter in Tertiary Niger Delta: Origin of Source rocks in a deltaic environment. *American Association of Petroleum Geologists Bulletin*. 73(3) 227 – 298.

Cantalamessa, G., Di Celma, C., & Ragaini, L. (2006). Tectonic controls on Sequence stacking pattern and along-strike architecture in the Pleistocene Mejillones Formation, northern Chile: implications for sequence stratigraphic models. *Sed. Geol.* 183, 125–144.

Cantalamessa, G., Di Celma, C., Ragaini, L., Valleri, G., & Landini, W. (2007). Sedimentology and high resolution sequence stratigraphy of the late Middle to Late Miocene Angostura Formation (western Borbón Basin, north-western Ecuador). *J. Geol. Soc. London*. 214 – 221.

Cohen, H. A., & McClay, K. R. (1996). Sedimentation and shale tectonic of the north-western Niger Delta front. *Marine and Petroleum Geology,* 13, 313 – 328.

Crews, J. R., Weimer, P., Pulham, A. J., & Waterman, A. S. (2000). Integrated approach to condensed section identification in intraslope basins, Pliocene–Pleistocene, Northern Gulf of Mexico. *American Association of Petroleum Geologists Bulletin*, 18(6), 1519 – 1536.

Delteil, J. R., Valery, P., Montadert, L., Fondeur, C., Patriat, P, & Mascle, T. (1974). The Continental Margin in the Northern part of the Gulf of Guinea. In: C. A. Burk, and C. L. Drake (Eds.), Geology of Continental Margins. New York, Springer – Verlag. 297 – 311.

Di Celma, C., Ragaini, L., Cantalamess, G., & Landini, W. (2005). Basin-physiography and tectonic influence on sequence architecture and stacking pattern: Pleistocene succession of the Canoa Basin (Central Ecuador). *Geological Society of America Bulletin,* 117, 1226 – 1241.

Doust, H., & Omatsola, M. E. (1990). Petroleum geology of the Niger Delta. In: J. Brooks (ed.) Classic petroleum provinces, Geological Society (London) Special Publication 50, 365 – 380.

Edwards, M. B. (1995). Differential subsidence and preservation potential of a shallow water Tertiary sequence, northern Gulf Coast Basin, USA. *Special Publication of International Association of Sedimentology,* 22, 265 – 281.

Emery, D., & Myers, K. (1996). Sequence stratigraphy. Blackwell Science Ltd., Oxford, 45 – 107.

Ejedawe, J. E. (1981). Patterns of incidence of oil reserves in Niger Delta Basin. *American Association of Petroleum Geologists Bulletin*, 65, 1574 – 1585.

Ekweozor, C. M., & Okoye, N. V. (1980). Petroleum Source-bed evaluation of Tertiary Niger Delta.American *Association of Petroleum Geologists Bulletin,* 64(8), 1250 – 1259.

Evamy, B. D., Haremboure, J., Kamerling, P., Knaap, W. A., Molly, F. F., & Rowlands, P. H. (1978). Hydrocarbon habitat of the Tertiary Niger Delta. *American Association of Petroleum Geologists Bulletin,* 62, 125 – 142.

Galloway, W. E. (1989). Genetic Stratigraphic sequences in basin analysis: architecture and genesis of flooding surface bounded depositional units. *American Association of Petroleum Geologists Bulletin*, 73, 125 - 142

Gino, C. (2007). Sedimentology and High-resolution sequence stratigraphy of the Late middle – Late Miocene, Angostura Formation (Western Borbon

Basin, northwestern Ecuador). *Journal of Geological Society,* 163, 101 – 117.

Haack, R. C., Sundaraman, P., Diedjomahor, J.O., Xiao, H., Gant, N.J., May, E.D., & Kelsch, K. (2000). The Niger Delta petroleum systems, Nigeria. In: Mello, M.R., Katz, B.J. (eds.), Petroleum Systems of South Atlantic Margins. *American Association of Petroleum Geologists Memoir*, 73, 213–231.

Haq, B. U., Hardenbol, J., & Vail, P. R. (1988). Mesozoic and Cenozoic Chronostratigraphy and eustatic cycles. In: C. A. Wilgus, B. S. Hastings, C. G. St. Kendail, H. W. Posamentier, C. A. Ross and J. C. Van Wagoner (eds.), Sea - level changes: An Integrated Approach. Gulf Coast Section Society of Economic Paleontologists and Mineralogists, 42(18), 40 – 45.

Hernández-Mendoz, J. I., Hentz, T. F., Deangelo, M. V., Wawrzyniec, T. F., Sakurai, S., Talukdar, S. C., & Holtz, M. H. (2008). Miocene chronostratigraphy, paleogeography and play framework of the Burgos Basin, Southern Gulf of Mexico. *American Association of Petroleum Geologists Bulletin*, 92(2), 1501– 1535.

Hosper, J. (1975). Gravity field and structure of the Niger Delta, Nigeria. *Bulletin of American Geological Society,* 76, 407 – 422.

Igarashi A., Numanami, H., Taschiya, Y., & Fukuchi, M. (2001). Bathymetric distribution of fossil foraminifera within marine sediment cores from the eastern part of LÜtzow-Holm Bay, East Antarctica, and its paleoceanographic implications. *Marine Micropaleontology,* 42, 125 – 162.

Imasuen, I. O. Okiotor, M. E., & Etobro, A. A. I. (2011). Reservoir Evaluation of Well A, Field Y, North- Eastern Niger Delta: A Case of Problematic sandstone. *Advances in Applied Science Research*, 2 (3), 114-126.

Mangerud, G., Dreyer, T., Soyseth, Martinsen, L., & Ryseth, A. (1999). High Resolution Biostratigraphy and Sequence Development of the Paleocene Succession, Grane Field, Norway. In: Underhill, J. R. (ed.) Development and Evolution of the Wessex Basin, Geological Society, London, Special Publications, 133, 167 – 184.

McNeil, D. H., Dietrich, J. R., & Dixon, J. (1990). Foraminiferal Biostratigraphy and Seismic sequences: examples from the Cenozoic of the Baeufort – Mackenzie Basin. In: Hemelben, M. A., Kaminski, W. K and Scott, D. B (eds.) Paleoecology, Biostratigraphy, Paleooceanography and Taxonomy of agglutinated Foraminifera. Kluwer Academic Publishers, Dordrecht, Canada, 563 – 580.

Merki, P. J. (1972). Structural geology of Cenozoic Niger Delta. In: T. F. J. Dessauvagie and A. J. Whiteman (eds.). African Geology, Ibadan, Nigeria, Ibadan University Press, 635 – 646.

Myers, K. J., & Milton, N. J. (1996). Concepts and Principles of Sequence Stratigraphy. In: O. Emery, and Myers (eds.), Sequence Stratigraphy, Blackwell Science Ltd., London, 11 – 44.

Nton, M. E., & Adesina, A. D. (2009). Aspects of structures and Depositional Environments of sand Bodies within Tomboy Field, offshore Niger delta, Nigeria. ZME – Materials and Geoenvironment, 56(3), 284 – 303.

Ogbe, E. G. (1982). The Biostratigraphy of the Niger Delta. *Nigerian Journal of Mining and Geology*, 18(2) 59 – 69.

Olaleye, B., Nwaufu, W. A., & Iwobi, O. C. (2000). Hydrocarbon exploration in the Middle Miocene lowstand facies tracts in the Central Niger Delta. *Nigerian Association of Petroleum Explorationists Bulletin*, 5(1), 61 – 71.

Onuoha, K. M., Opera, O. I., Anowai, C., Mba, R. O., & Onu, N. N. (2008). Overpressure and Trap Integrity Studies in Parties of the Niger Delta Basin: Implication for Hydrocarbon Prospective. *Nigerian Association of Petroleum Explorationists Bulletin*, 20(2), 24 – 46.

Owolabi, O. O., Okpobiri, G. A., & Obomanu, I. A. (1990). Prediction of abnormal pressure in Niger Delta Basin using well logs. Procedure 13th Annual International Conference, *Nigerian Society of Petroleum Engineers. Nigeria,* 47 – 65.

Owoyemi, A. O., & Willis, B. J. (2006). Depositional patterns across syn-depositional normal faults, Niger Delta, Nigeria. *Journal of Sedimentary Research*, 76, 346 – 363.

Oyede, A. C., Giwa, G. O., & Okosun, E. A. (2005). Emergency Trends in the Application of Biostratigraphy to Petroleum Exploration and production. *Nigerian Association of Petroleum Explorationists Bulletin*, 18(1), 12 – 23.

Ozumba, M. B. (1999). Middle to Late Miocene Sequence Stratigraphy of Western Niger Delta. *Nigerian Association of Petroleum Explorationists Bulletin*, 13(2), 176 – 192.

Petters, S. W. (1982). Central West Africa Cretaceous - Tertiary Benthic Foraminifera and Stratigraphy. *Paleontolographica Abt,* A. Bd. 179, Lfg 1-3,15pl, 22figs, 1 – 104.

Rider, M. H. (2006). The Geological Interpretation of Well logs. Whittles Publishing, Roseleigh House, Latheronwheel, Scotland, 1 – 280.

Reijers, T. J. A., Petters, S.W., & Nwajide, C. S. (1996). The Niger Basin. In: T. J. A. Reijers, Selected chapters on Geology. Shell Petroleum Development Company Nigerian Publication, 105 – 114.

Schlumberger, I. (1985). Understanding of Well Evaluation, Gulf Publishing, Houston, 1-129.

Short, K. C., & Stauble, A. J. (1967). Outline of Geology of Niger Delta. *American Association of Petroleum Geologists Bulletin*, 51, 761 – 779.

Stacher, P. (1995). Present understanding of the Niger Delta hydrocarbon habitat. In: M. N. Oti and G. Postma (eds.), Geology of Delta. Balkema Publishers, Rotterdam, 257 – 267.

Stainforth, R. M., Lamb, R. M., Luterbacher, H., Bread, J. H., & Jeffords, R. M. (1975). Cenozoic Planktic Foraminiferal Zonation and Characteristics of index forms. University of Kansas. Paleontologic Contributions, Lawrence, Kansas, 62, 1 – 425.

Storms, J. E., & Swift, D. J. P. (2003). Shallow-marine sequences as the building blocks of stratigraphy: insights from numerical modelling. *Journal of Basin Research*, 15, 287 – 303.

Tegbe, O. O., & Akaegbobi, I. M. (2000). Reservoir Heterogeneities as a controlling factor to the abnormal production performance of the oil field Y, North-eastern Niger Delta. *Nigerian Association of Petroleum Explorationists Bulletin*, 15(1), 81 – 91.

Vail, P. R., & Wornardt, W. (1991). An integrated Approach to Exploration and Development in the 1990's: well log, seismic, sequence stratigraphic analysis. *Trans Gulf Coast Assoc. Geol. Soc.*, 61, 630-649.

Weber, K. J. (1971). Sedimentological aspects of oil Fields in Niger Delta. *Geology Magazine*, 105, 386 – 397.

Whiteman, A. J. (1982). Nigeria, its Petroleum geology, resources and potential: London, Graham and Trotman, 394.

Zecchin, M., Mellere, D., & Roda, C. (2006). Sequence stratigraphy and architectural variability in growth fault-bounded basin fills: a review of Plio-Pleistocene stratal units of the Crotone Basin, southern Italy. *Journal Geol. Soc. London*, 163, 471–486.

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